FACILITY FORM 602

N70-75243
(ACCESSION NUMBER) (THRU)

55 1
(PAGES) (CODE)

CR-110068
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)

MODEL 8533
THRUST CHAMBER INJECTOR
COMBUSTION STABILITY EVALUATION

Report No. 8533-910012

December 1967

BELL AEROSYSTEMS - A TEXTRON COMPANY

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1.0 INTRODUCTION AND SUMMARY

The purpose of this effort was to evaluate thrust chamber injector stability characteristics, without and with combustion oscillation suppression devices, when pulsed with explosive charges.

Two injectors were utilized for this program: an existing modified, Model 8096 16K thrust unit, previously tested during Phase I and, an 18K thrust unit designed to satisfy the Model 8533 performance and heat rejection objectives.

Static nonfiring type tests were conducted first to determine the effects of explosive charge detonation on pressure rise and hardware durability. Fire tests were then conducted to establish baseline performance and determine unsuppressed and suppressed combustion stability characteristics when pulsed with explosive charges.

Static tests were performed utilizing a surplus injector assembled with a steel wall start chamber and aluminum nozzle. Six tests were accomplished with radially oriented explosive charges ranging from 7.9 grains to 100 grains. Pressure rise pulses of from 137 to 1470 psi above the nominal 500 psi, helium, chamber pressure were observed. Injector face damage was sustained with the 15 grain unit which became more severe with increasing bomb size. This damage was attributed to impact of the Teflon charge case fragments on the injector face.

The 16K thrust injector, S/N 4B, was fire tested without a suppression device or bomb. This test was terminated prematurely due to injector face burnout resulting from combustion instability.

Injector S/N 8, the 18K unit was then subjected to fire test evaluation. Characterist velocity c* performance data was obtained over a range of mixture ratio on short duratio (1.5 second) fire tests. Then this unit was pulsed with a 7.9 grain charge, after 0.500 seconds duration of rated chamber pressure. Combustion oscillations, characteristic of the first tangential mode were sustained.

A start chamber with an acoustic suppression device incorporated in the uncooled chamber wall, at the injector end, was installed and the 7.9 grain bomb test repeated. Combustion oscillations (first tangential mode) were again sustained, however, the peak pressure was reduced to a value of approximately 60 percent of that which was observed from the previous unsuppressed test.

An additional fire test of 1.5 seconds duration was conducted to verify acoustic cavity gas temperatures. These temperatures which were predicted to be 1480°F, indicated values of approximately 2450°F and some localized overheating and melting of the acoustic orifices was observed.

A three-inch long, four vaned baffle was installed on the injector and a series of six, 0.500 seconds duration fire tests were accomplished with bomb charge sizes ranging from 7.9 to 100 grains. An axial bomb installation was used for charges of 40 grains and greater, to preclude possible injector face damage. Combustion oscillations were damped out on all tests of this series. The oscillations were attenuated to the pre-bomb level in 9 and 20 milliseconds for the 7.9 and 100 grain charge sizes, respectively.

It is recommended that further effort be expended in Phase II for both the baffle and acoustic cavity devices. For the baffle it is proposed to incrementally reduce the vane length to determine the minimum value which damps out combustion oscillations. For the acoustic device it is proposed to compartment the cavity volume to achieve a static condition which is expected to enhance its damping capability.

2.0 DESIGNS

2.1 Start Chamber Design

The basic injector-start chamber assembly shown in Figure 1, consists of injector with an oxidizer manifold, 68 inch L* heat sink chamber, and water cooled nozzle. A heat sink type copper nozzle was used for all 18K thrust tests instead of the water cooled nozzle shown, since a water cooled nozzle of the Model 8533 dimensions was not available. The copper nozzle had a throat area eight percent larger than required for the 18K thrust flow rates so that chamber pressure was lower than the nominal 500 psia. The heat sink capability of the nozzle limited the performance test run durations to approximately 1.5 seconds of steady-state chamber pressure.

2.2 Bomb Design

Two bomb designs were utilized during this test program. Both designs utilized an electrical detonating No. 5 blasting cap, which contained 7.9 grains of explosive, a Teflon charge holder, a mounting boss and an electrical gland assembly.

The Radial Bomb (Figure 2) P/N 8533-470008 was mounted 3.4 inches from the injector face with a constant center of charge distance from the chamber wall of 1.34 inches. C-4 explosive material was added to the basic No. 5 detonating cap to give the total charge weight. The Teflon charge holder had a constant 0.25 inch wall thickness by having different I.D. and O.D. dimensions for the various charge sizes. Thermal insulation for the detonating cap was provided by air gap and Teflon insulators. Gas sealing was accomplished by soft copper gaskets and a neoprene o-ring type seal in a standard Conax thermocouple gland assembly.

The axial bomb (Figure 3) P/N 8533-470014 was mounted through the chamber wall with a boss located as close to the injector as possible, the same location as the radial bomb, but due to the 90° offset configuration the center of charge was 5.4 inches from the injector face. The 1.34 inch distance from the chamber wall was maintained in this design. Based on the radial charge shrapnel damage observed during the static bomb tests, the axial bomb placed the charge further from the injector face and utilize

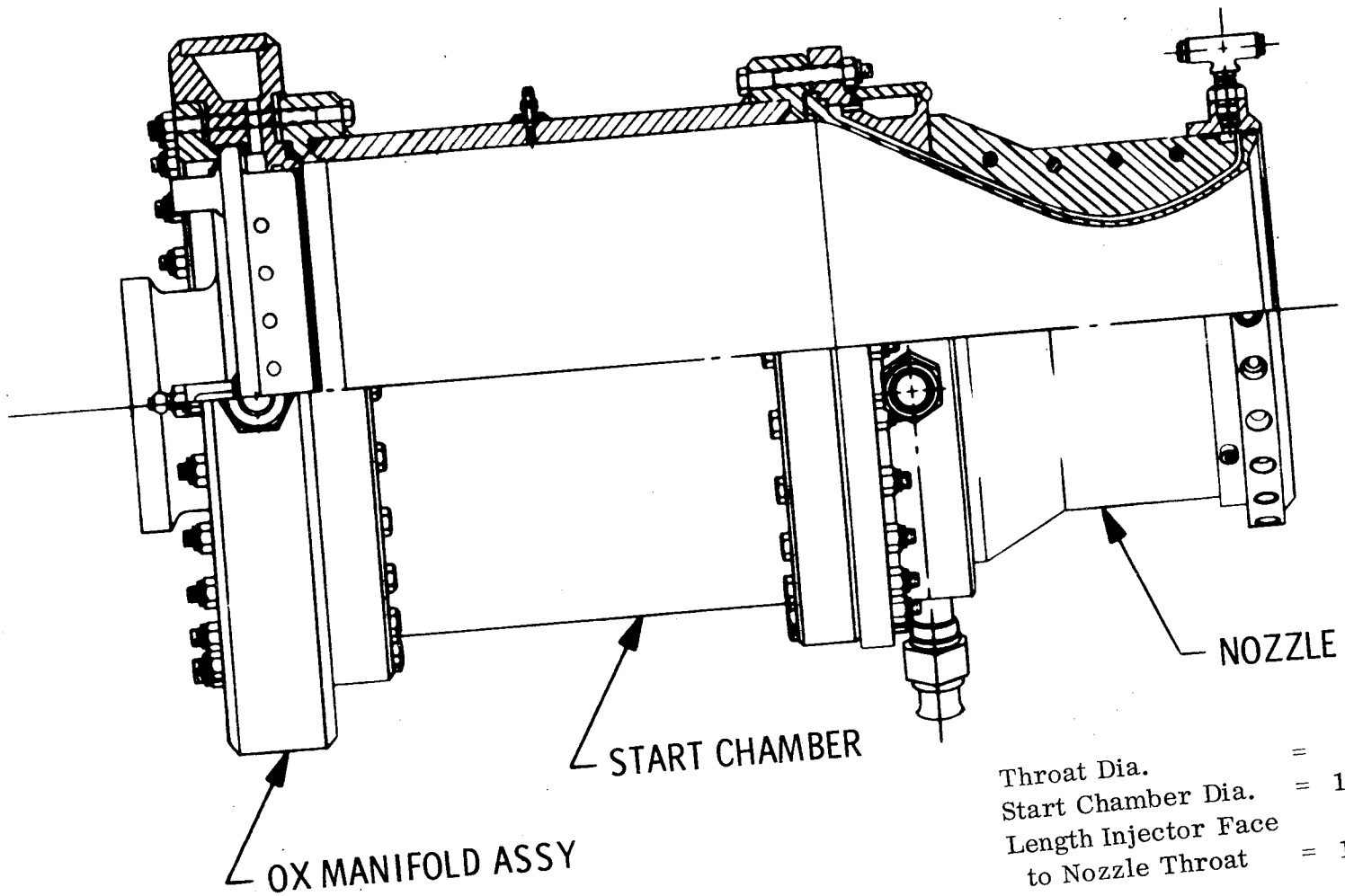

NOZZLE
START CHAMBER
OX MANIFOLD ASSY
Throat Dia. = 4.91 in.
Start Chamber Dia. = 10.8 in.
Length Injector Face to Nozzle Throat = 17.1 in.

Figure 1. Start Chamber Assembly

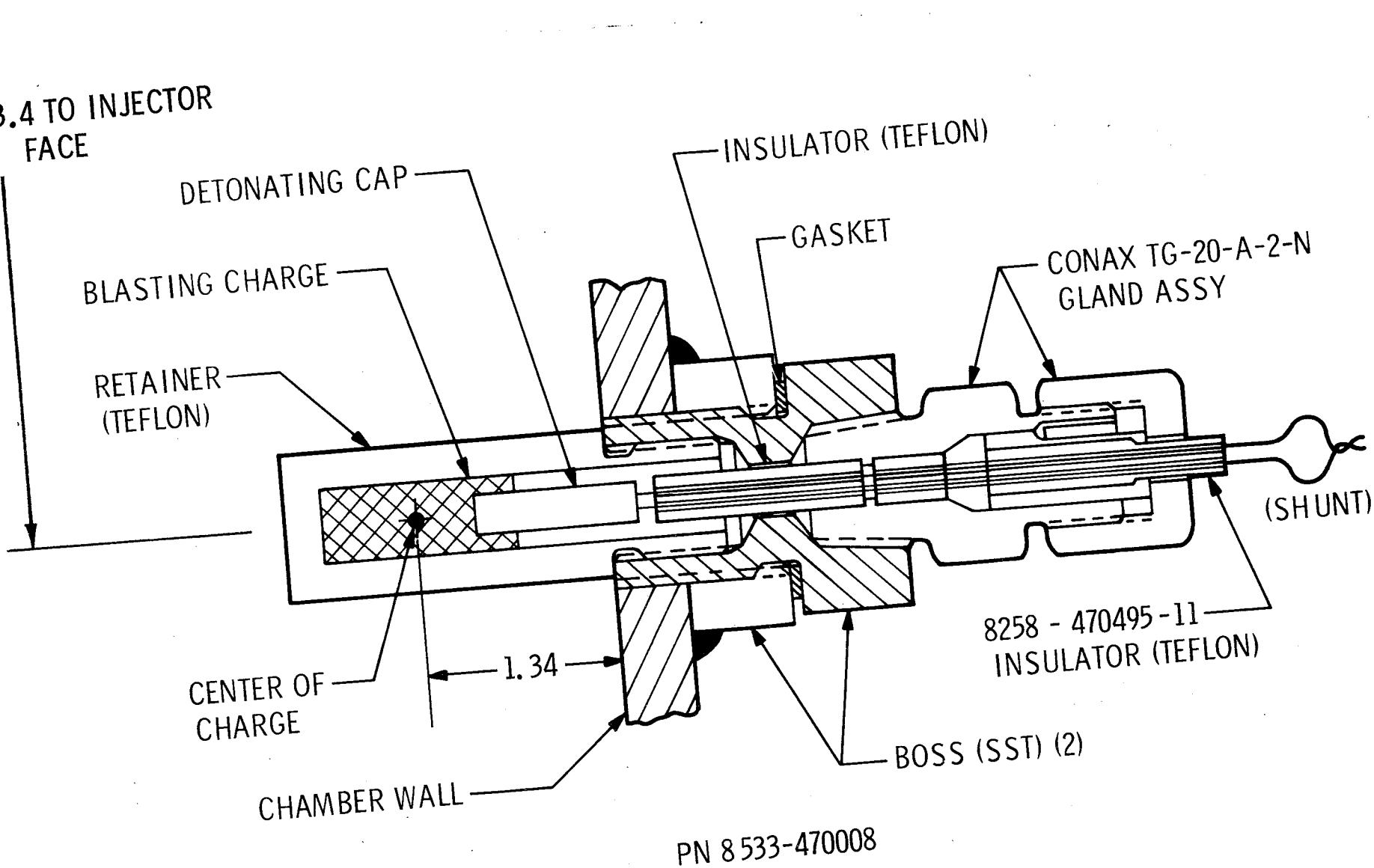


Figure 2. Radial Bomb Design

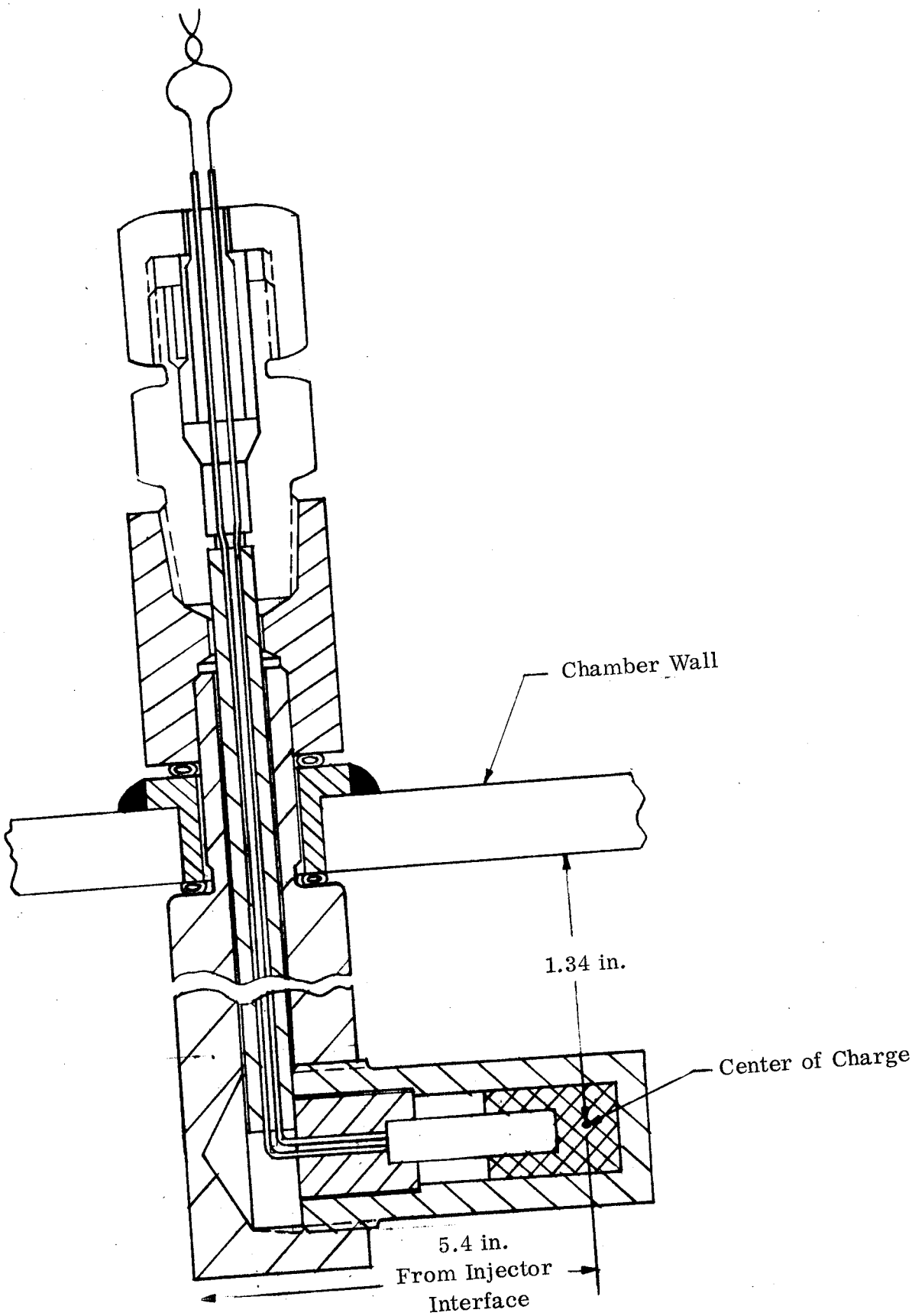


Figure 3. Axial Bomb Design

a 90° stainless steel boss assembly as a shrapnel shield. The Teflon charge holder wall thickness was a constant 0.20 inch for all bomb sizes.

2.3 Injector Design

The two injectors utilized for this program were originally P/N 8096-473001 and were modified for use on the Model 8533 program.

S/N 4B, formerly S/N 627 from the Model 8247 program, was modified to the S/N 4B configuration by adding 16 additional barrier doublets. It was utilized for preliminary injector evaluation during Phase I accumulating 24 start chamber type firing tests.

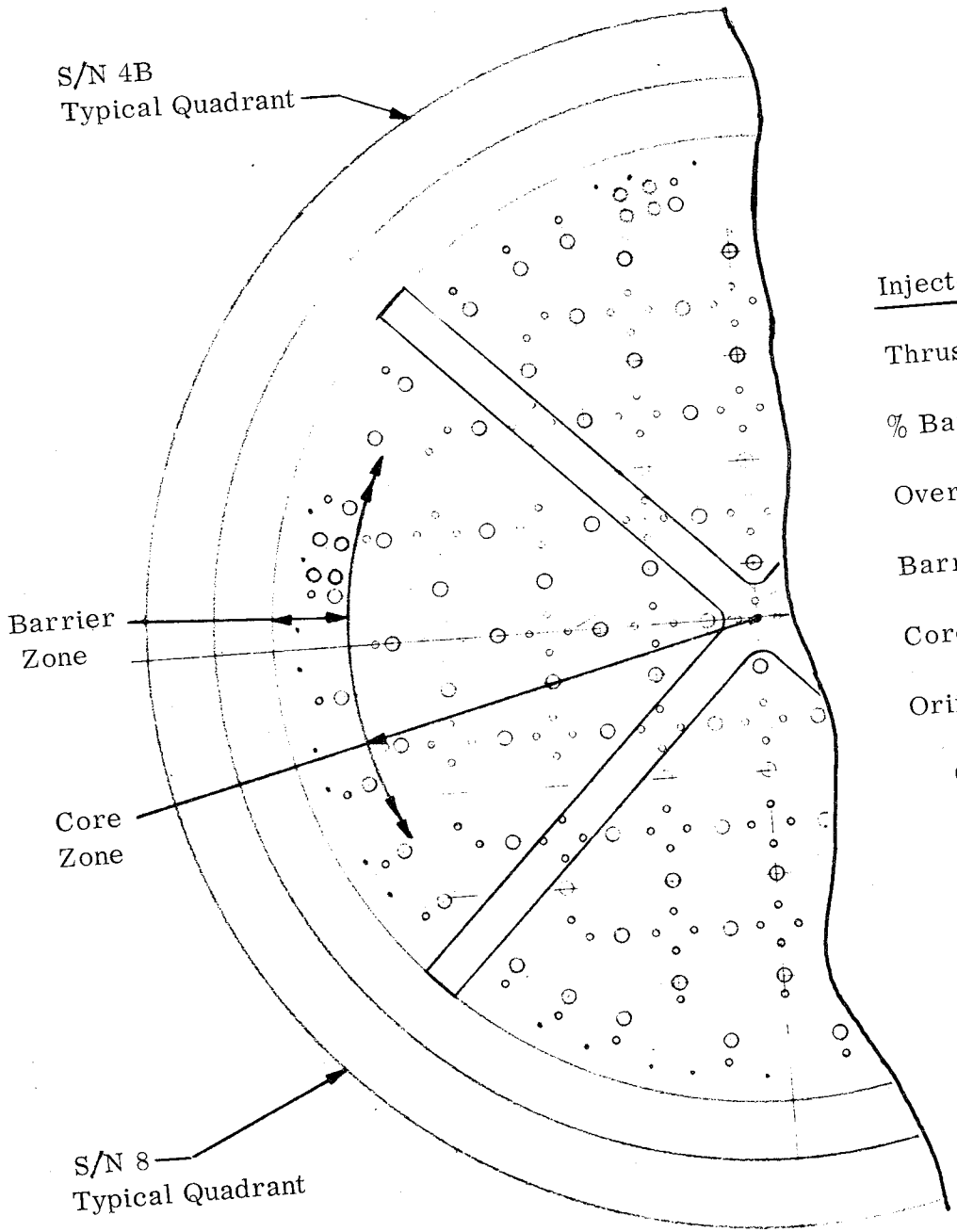
S/N 8 injector was formerly S/N 593 from the Model 8096 program and was modified by enlarging the fuel barrier and primary orifices, to operate at the 18K thrust level at the performance objective predicted for the Model 8533 prototype injectors.

A comparison of the two injector designs is shown in Figure 4.

2.4 Combustion Instability Suppression Device Design

Two types of suppression devices were utilized for evaluation in the event that the bare grid type injector design became unstable from a bomb induced disturbance. The devices, an acoustic damper and a baffle, were designed to suppress the first tangential mode characteristic frequency. Stability mode frequencies calculated, assuming a speed of sound in the combustion zone of 3990 ft/sec, are included in Table I. The sonic speed was based on data obtained on an unstable run of S/N 5A injector during Phase I testing in which a first tangential 2600 cps frequency was observed.

The acoustical damper design shown in Figure 5 consists of 600(0.0995 in. dia.) holes in the chamber wall of an existing start chamber. An acoustic cavity manifold cover enclosed these orifices giving a common backing volume. The spacing and size of the acoustic orifices was dictated by the location of the coolant passages on the proposed Model 8533 regeneratively cooled aluminum thrust chamber. Design of the acoustic damper includes tuning to a given frequency produced by the combustion oscillations as follows:



Injector	S/N 4B		S/N 8	
Thrust	16K		18K	
% Barrier	20.7		18.0	
Overall O/F	1.9		1.9	
Barrier O/F	1.05		0.94	
Core O/F	2.26		2.26	
Orifices:	No.	Dia.	No.	Dia.
Ox Core	88	0.111	88	0.111
Ox Barrier	32 16	0.072 0.051	32	0.072
Fuel Core	176	0.057	176	0.061
Fuel Barrier	32 16	0.085 0.059	32	0.096
Fuel Film	32	0.026	32	0.026

4. Injector Design Characteristics

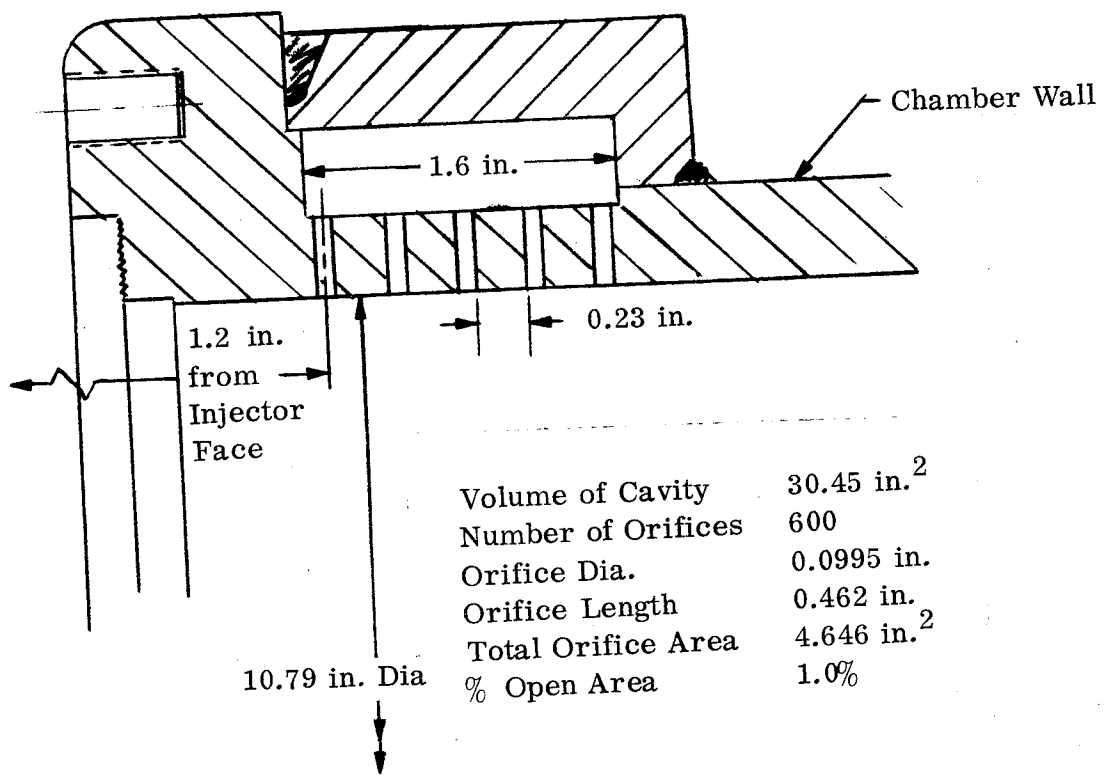


Figure 5. Acoustic Cavity Design

TABLE I

MODEL 8533 STABILITY MODE CALCULATIONS

MODE	FREQUENCY*
1 - TANGENTIAL	2600 CPS
2 - TANGENTIAL	4310 CPS
3 - TANGENTIAL	5935 CPS
1 - RADIAL	5412 CPS
2 - RADIAL	9920 CPS
1 - LONGITUDINAL	1742 CPS
2 - LONGITUDINAL	3484 CPS
3 - LONGITUDINAL	5226 CPS

* ASSUMES SPEED OF SOUND BASED ON S/N 5A FREQUENCY DATA - 3990 FT/SEC

$$f = \frac{a\ (12)}{2\ \pi} \sqrt{\frac{A}{L_{eff}\ V}}$$

where

f = frequency of the cavity - 2600 cps

a = speed of sound in the cavity

A = the open area of the orifices

L_{eff} = the effective orifice length

V = the backing volume of the absorption chamber.

The L_{eff} used for this design was L+0.5d where L is the length and d is the diameter of the orifices. The speed of sound in the cavity is a function of the molecular weight and temperature of the cavity gas. An O/F ratio = 0.95 was used with a predicted temperature of 1480°F.

The baffle design was a heat sink type fabricated of stainless steel and bolted to the injector.

Since the first tangential was the predicted mode of instability, a four vaned baffle was utilized as shown in Figure 4. This baffle configuration is shown to be adaptable to the grid type injector such that none of the propellant orifices were blocked except for 8 fuel film orifices (two near each of four vane tips). A 3.0 inch baffle length was determined to be adequate to cover the sensitive zone and disrupt tangential oscillations based on the analysis performed by Dynamic Sciences Corp. as shown in Figure 6. This length was also compatible with an integral oxidizer regeneratively cooled aluminum configuration for which preliminary design was previously completed. The injector-baffle installation is shown in Figure 7. A photograph of the injector and baffle under water flow test is shown in Figure 8.

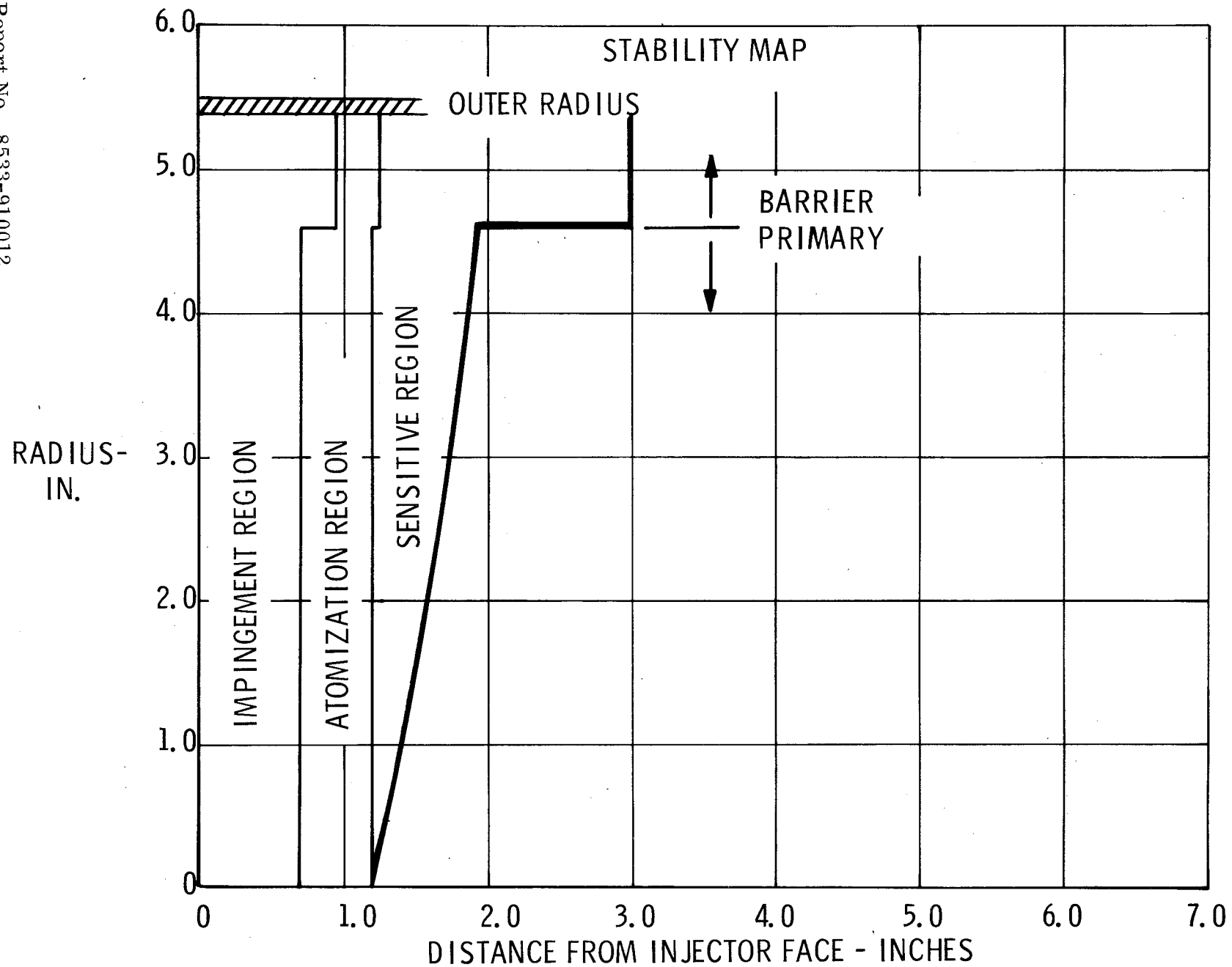


Figure 6. Sensitive Region Map (Dynamic Sciences)

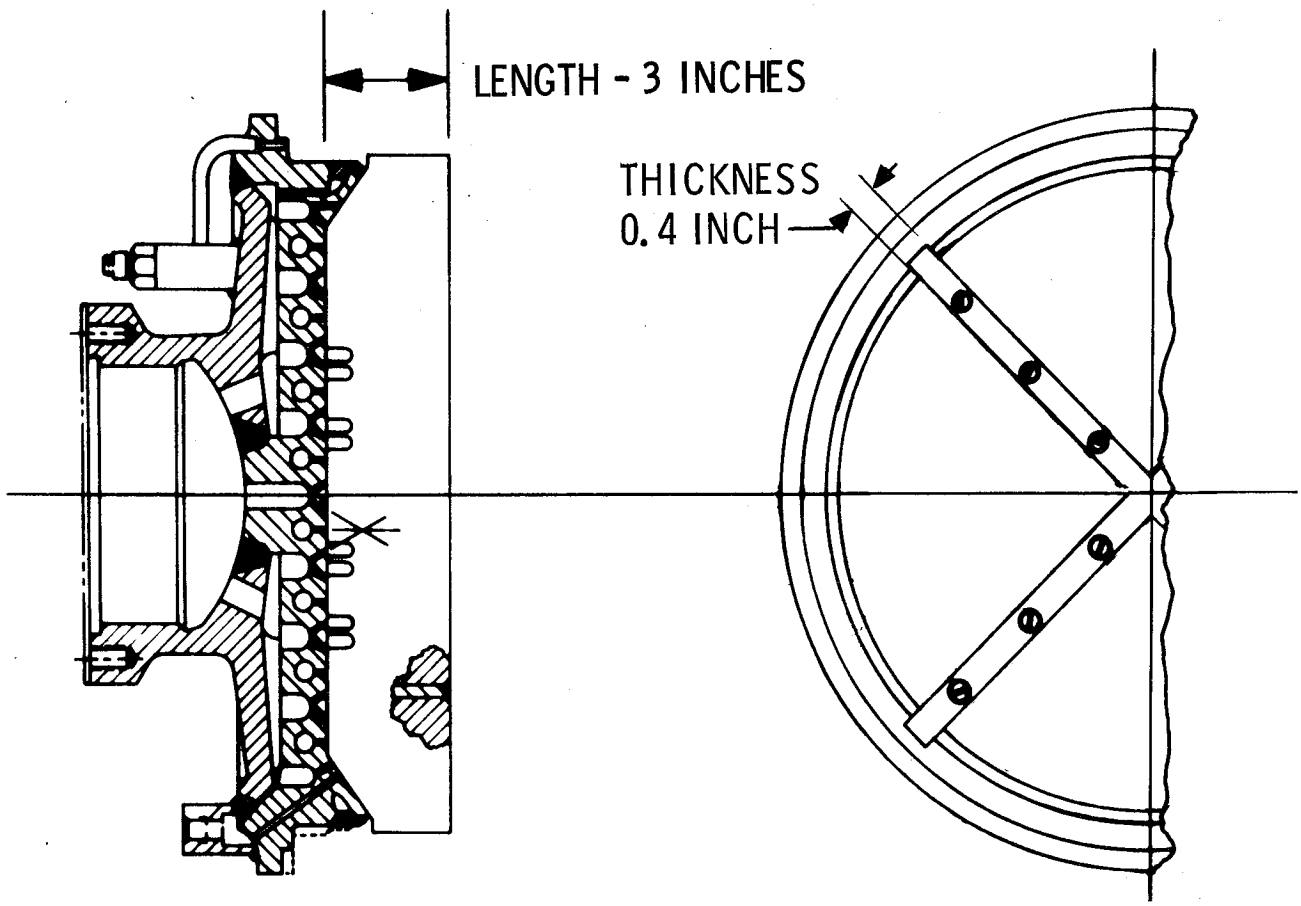


Figure 7. Baffle Installation

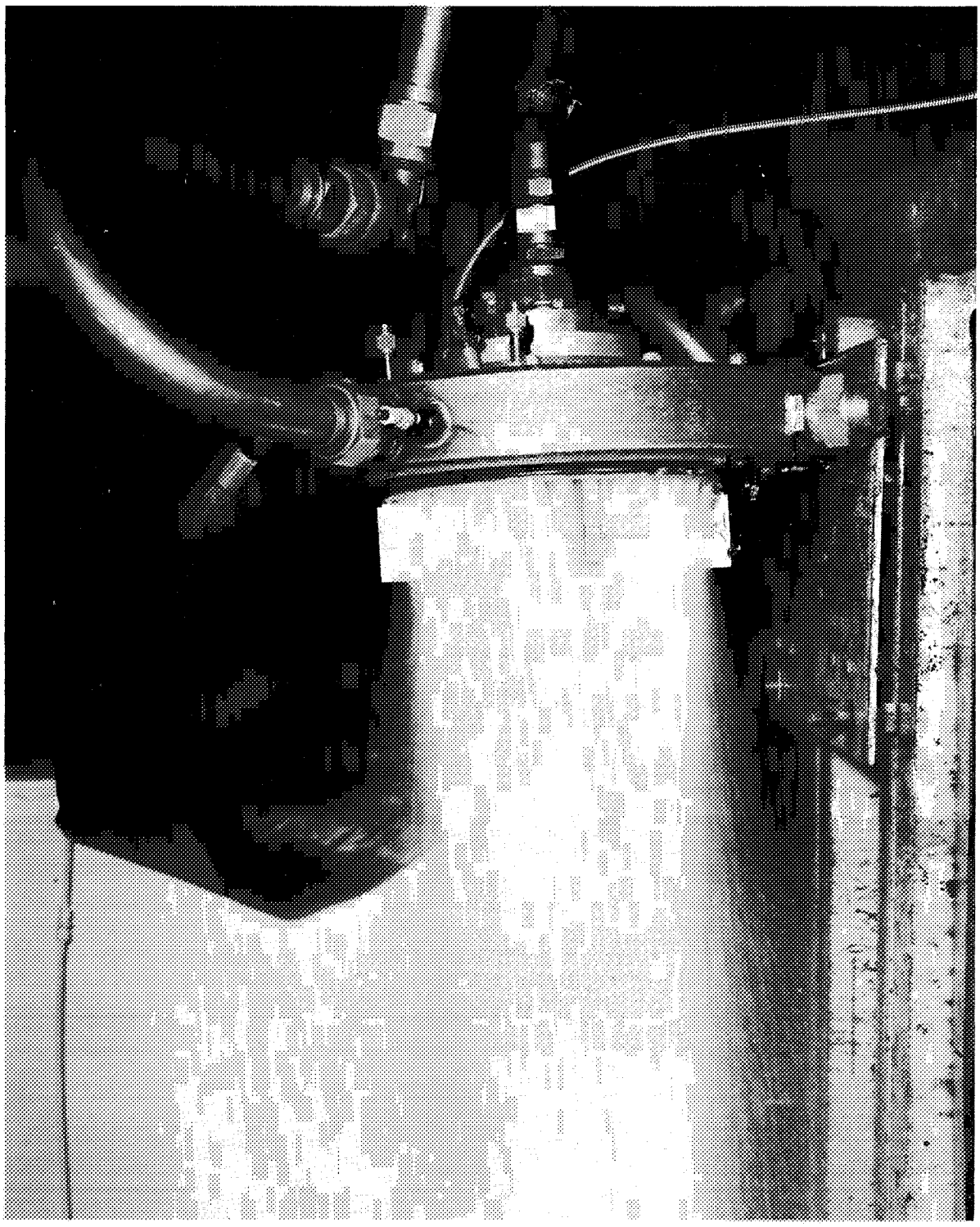


Figure 8. Baffle Photo (Installed Under Flow Test)

3.0 EVALUATION

This section contains a discussion of the evaluation effort. Static (nonfiring) and fire tests were performed at Bell Test Center, Test Cell 2CS-1. A test summary is presented in Table II. The test cell schematic for injector fire test is shown in Figure 9. Fuel and oxidizer propellants are supplied to the feed system from nitrogen gas pressurized tankage. Propellant flow control is accomplished with cavitating venturi installed immediately upstream of the stand valves. Nitrogen gas purges, sequenced by check valve action, are introduced into the oxidizer stand valve and the injector fuel manifold.

Fire test sequence is initiated by energizing the oxidizer stand valve which allows propellant flow to the injector. The oxidizer manifold pressure actuates at 30 psia and thus provides an oxidizer lead, and in turn signals the fuel valve pilot operated solenoid valve. The fuel valve-in-head actuation pressure increases forcing the valve open, allowing fuel to flow into the injector. Ignition takes place and thrust chamber pressure increases. Actuation of the thrust chamber pressure switch at 375 psia completes the start sequence.

Shutdown is accomplished by simultaneous removal of electrical power from both the fuel pilot operated solenoid valve and oxidizer stand valve. Differential closing of the fuel valve-in-head and oxidizer stand valve provides an oxidizer override. During bomb pulse tests, shutdown and bomb detonation were simultaneously signalled which provided an interval of 25 milliseconds (nominal) between the bomb pulse and shutdown for tests 2CS1-59, 60 and 61. For subsequent tests, the pilot operated solenoid valve was replaced with a solenoid valve P/N (8081-472045) which yielded a corresponding shutdown interval of 90 milliseconds.

The high frequency instrumentation schematic is shown in Figure 10. Thrust chamber pressure transducers installed in ports through the chamber wall, were Kistler Model 616 F4. Accelerometers, installed on the injector aft cover, were Endevco Model 2224C.

TABLE II

TEST SUMMARY

	Run No. 2CS1	Injector S/N	Run Duration sec	P_c Chamber Pressure psia	Mixture Ratio O/F	c^*_{cor} ft/sec (2)	Bomb Charge Grains	Suppress Device	Remarks
Static Tests	44	1	N.A. (1)	500 psia He	N.A.	N.A.	7.9	None	
	45						15		Very Slight Face Shrapnel Damage.
	46						20		Observed Injector Face Shrapnel Damage.
	47						40		Damage Severity Increasing.
	48						80		Damage Severity Increasing.
	49	1	N.A. (1)	500 psia He	N.A.	N.A.	100		Damage Severity Increasing.
Fire Tests	50	4B	2.67	No Data	1.90	No Data	None		Unstable - Injector Face Burnout
	51	8	No Ignition	-	-	-			Stability Monitor Shutdown Malfunction
	52		2.21	450	1.92	5509			Checkout
	53		1.65	98	1.93	Transient			Stability Monitor Shutdown
	54		1.59	85	2.06	Transient			Stability Monitor Shutdown
	55		3.4	460	1.90	5547			
	56		3.4	474	1.76	5615			
	57		No Ignition	-	-	-			Malfunction-Fuel Valve Failure
	58		3.8	464	2.01	5531	None		
	59		2.7	458	1.91	5536	7.9	None	Unstable
	60		2.4	461	1.93	5517	7.9	Acoustic	Unstable
	61		3.6	464	1.93	5562	None	Acoustic	
	62		2.5	465	1.92	5516	7.9	Baffle	Stable
	63		2.6	466	1.91	5523	15		
	64		2.9	462	1.91	5495	20		
	65		2.7	467	1.93	5507	40		
	66		2.8	464	1.91	5518	60		
	67		2.7	464	1.92	5522	80		
	68		2.8	467	1.93	5508	100		Stable

Notes (1) NA Denotes Not Applicable

(2) Corrected to Nozzle Inlet Conditions: $c^*_{cor} = 0.992\ c^*$ Test

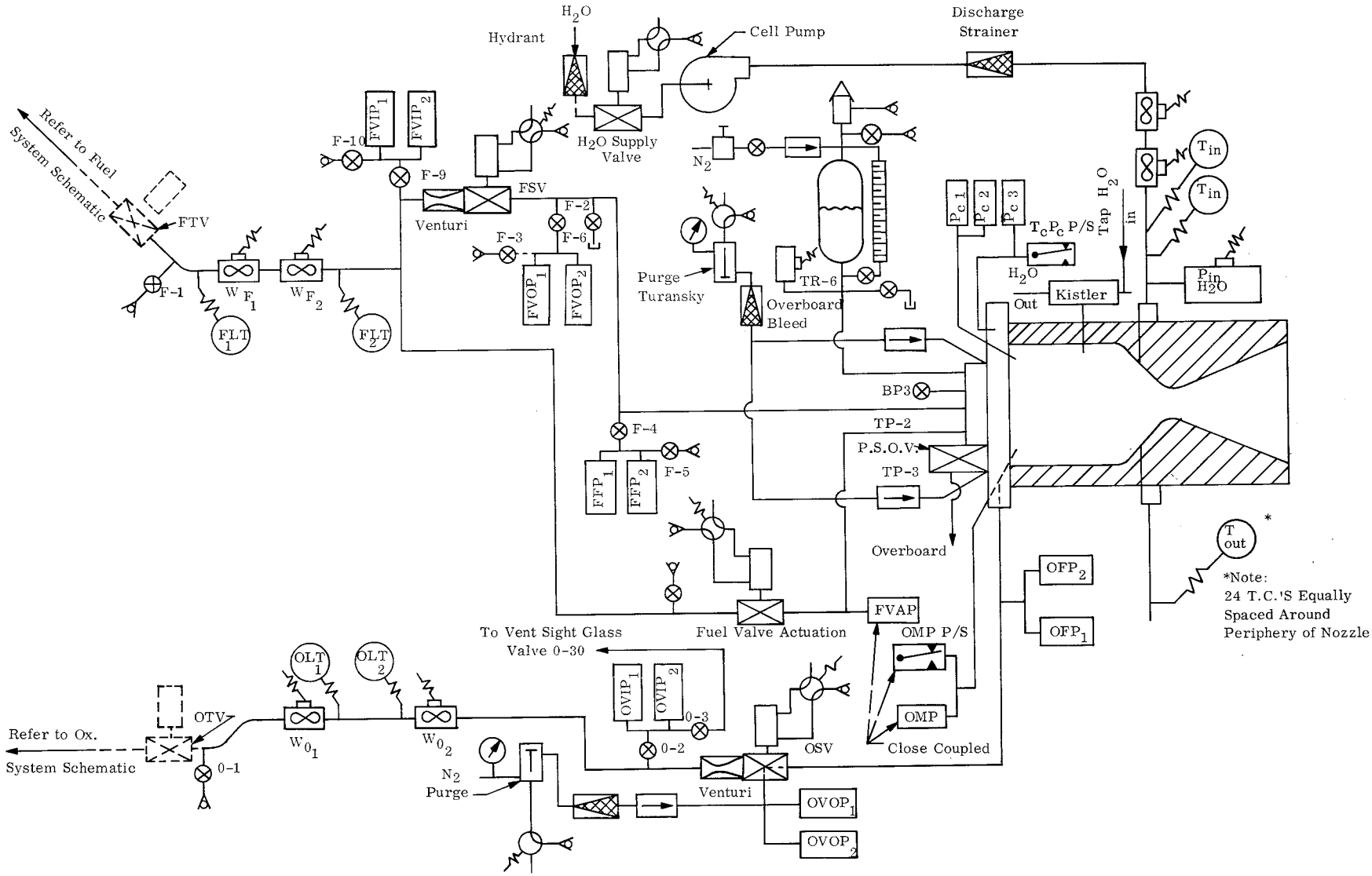
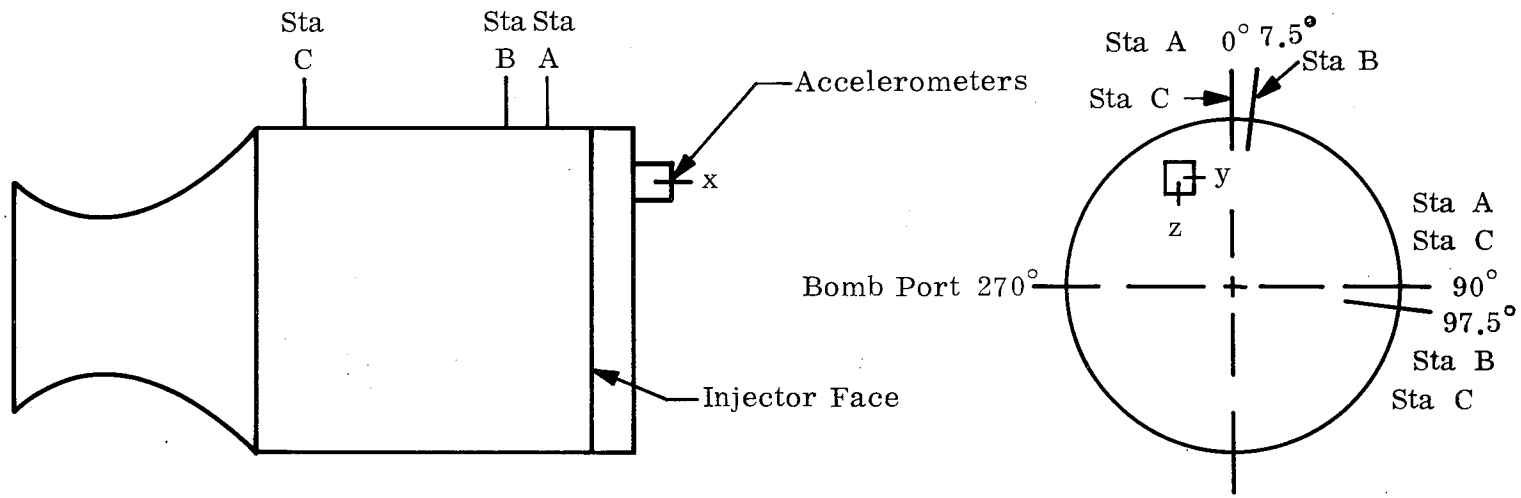


Figure 9. Injector Test Schematic



Pressure Transducer Location

Station A - 2.6 inches from injector face
Station B - 3.4 inches from injector face
Station C - 2.5 inches from start of nozzle

Bomb Location

Radial - Sta B

Axial - Sta B + 2.0 in.

Figure 10. High Frequency Schematic

3.1 Static Bomb Tests

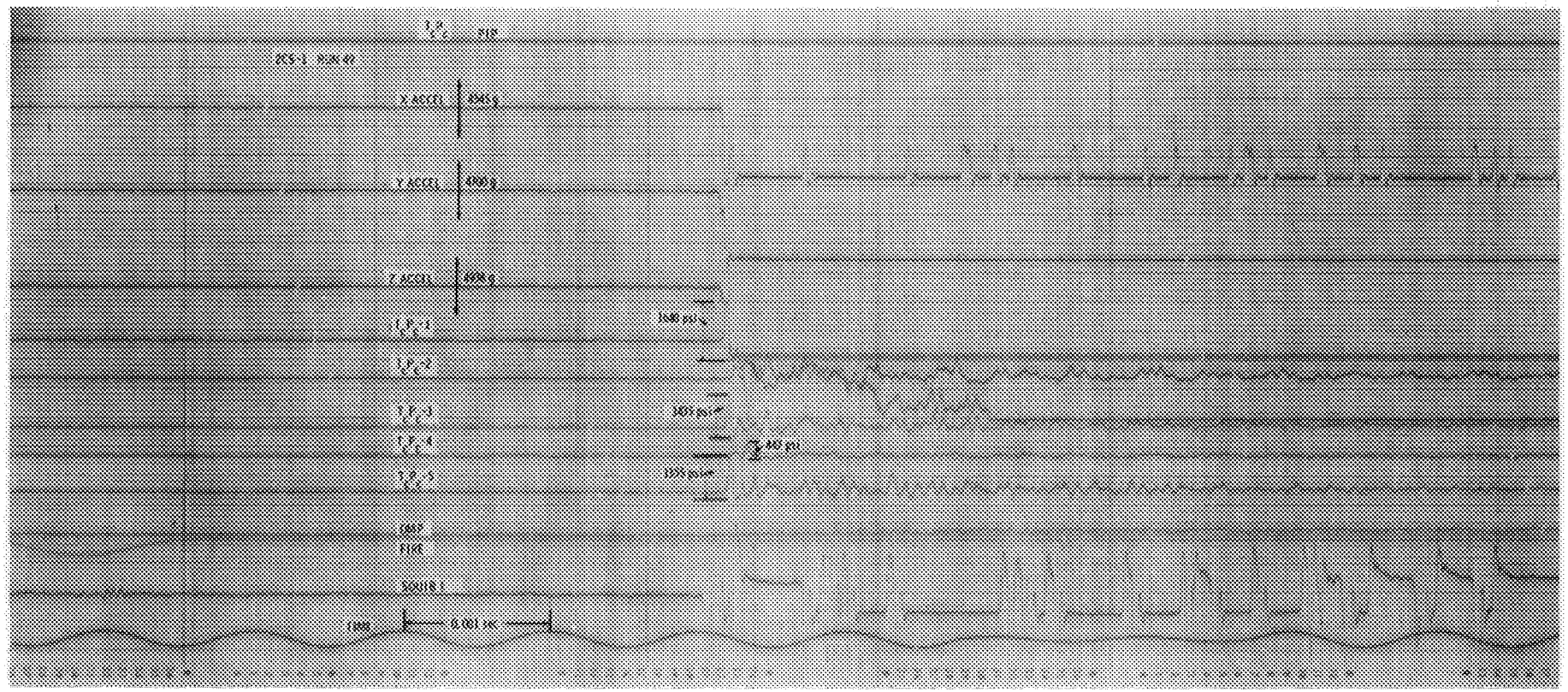
These tests were conducted with a surplus aluminum injector and nozzle, with a steel wall start chamber. A throat plug was utilized and the chamber was pressurized to 500 psia with helium gas for each test. Bomb sizes from 7.9 grains to 100 grains were electrically detonated using the radial bomb design, in tests 44 through 49. The FM playback for test 49, which was of 100 grain charge size is shown in Figure 11 All accelerometer transducer amplifiers became saturated upon bomb detonation during this and the previous test. $T_c P_c$-1 pulse pressure rise and acceleration measured for all static bomb tests is presented in Table III. The disturbance is shown to increase with charge size, except for test 49, which showed a slightly lower pulse rise. However, $T_c P_c$-5 indicated more typical pressure pulse rised of 1045 and 1200 psi for test 48 and 49, respectively.

TABLE III

STATIC BOMB TEST RESULTS

Test No. 2CS1	Bomb Size Grains	$T_c P_c$-1 Pressure Rise P_c psi	Axial Acceleration Ax g(D.A.)
44	7.9	137	453
45	15	228	450
46	20	297	500
47	40	310	400
48	80	1470	2000
49	100	1142	2000

The chamber wall and the aluminum nozzle were undamaged during these tests; however, severe damage to the aluminum injector face was observed. Figures 12 through 19 show the cumulative effect of shrapnel damage due to the teflon charge holder fragmentation. The first indication of damage (very slight) occurred after the 15 grain bomb size, see Figure 14, and increased in severity with increasing charge size. Also, it is shown that the injector damage area was aligned with the bomb port on the chamber wall. Based on these tests, a radial bomb 3.4 inches from the injector face is recommended only for bomb sizes less than 40 grains.



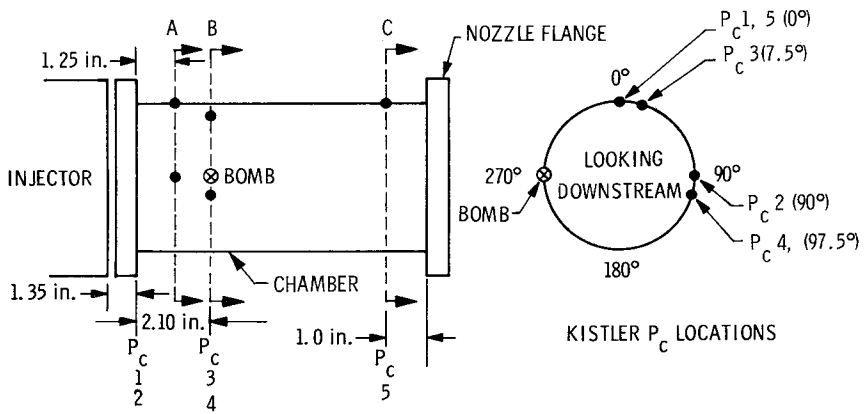


Figure 11. FM Playback Run No. 49

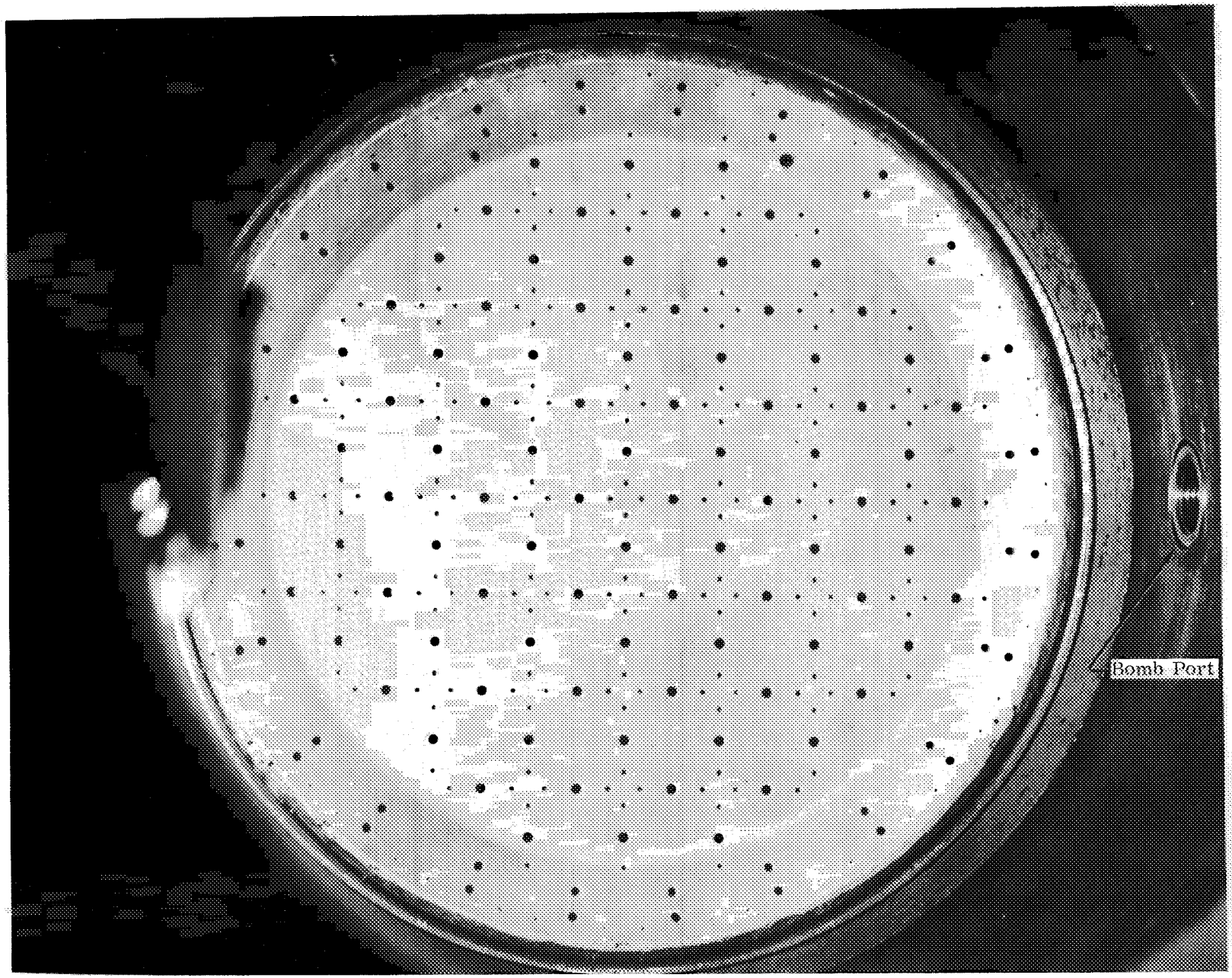


Figure 12. Injector Face Condition Pretest

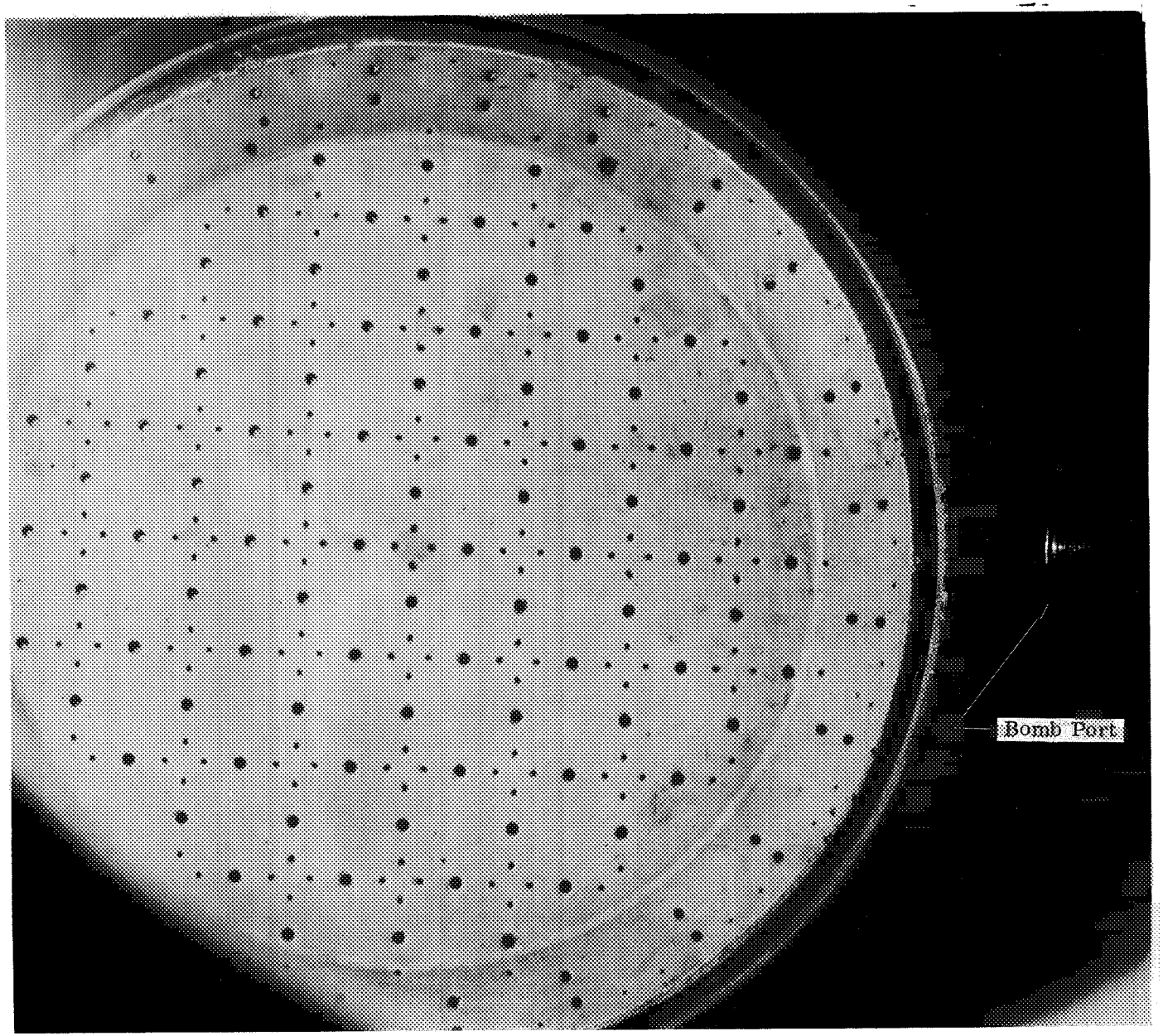


Figure 13. Injector Face Condition Post Test 44 (7.9 Grain Bomb)

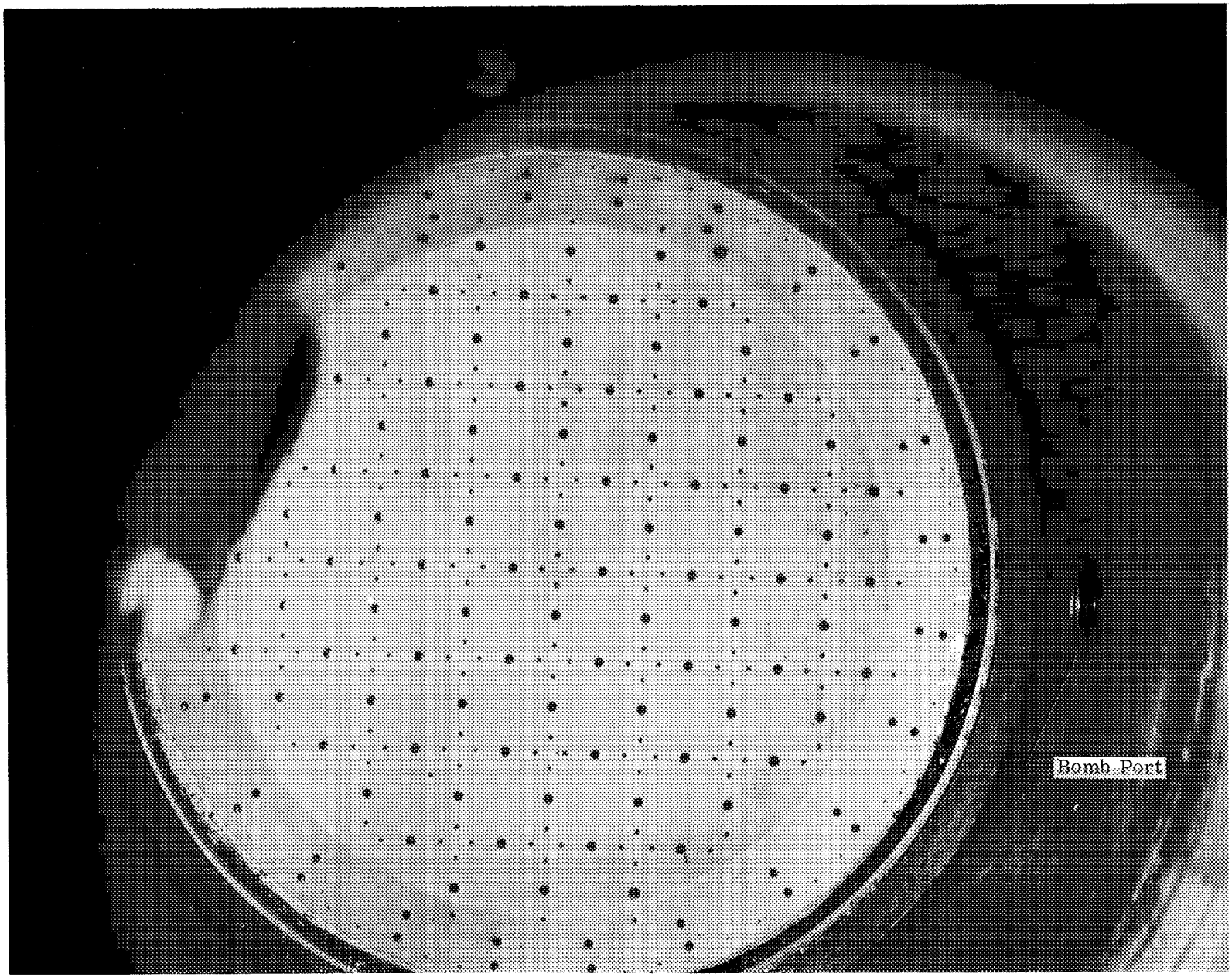


Figure 14. Injector Face Condition Post Test 45 (15 Grain Bomb)

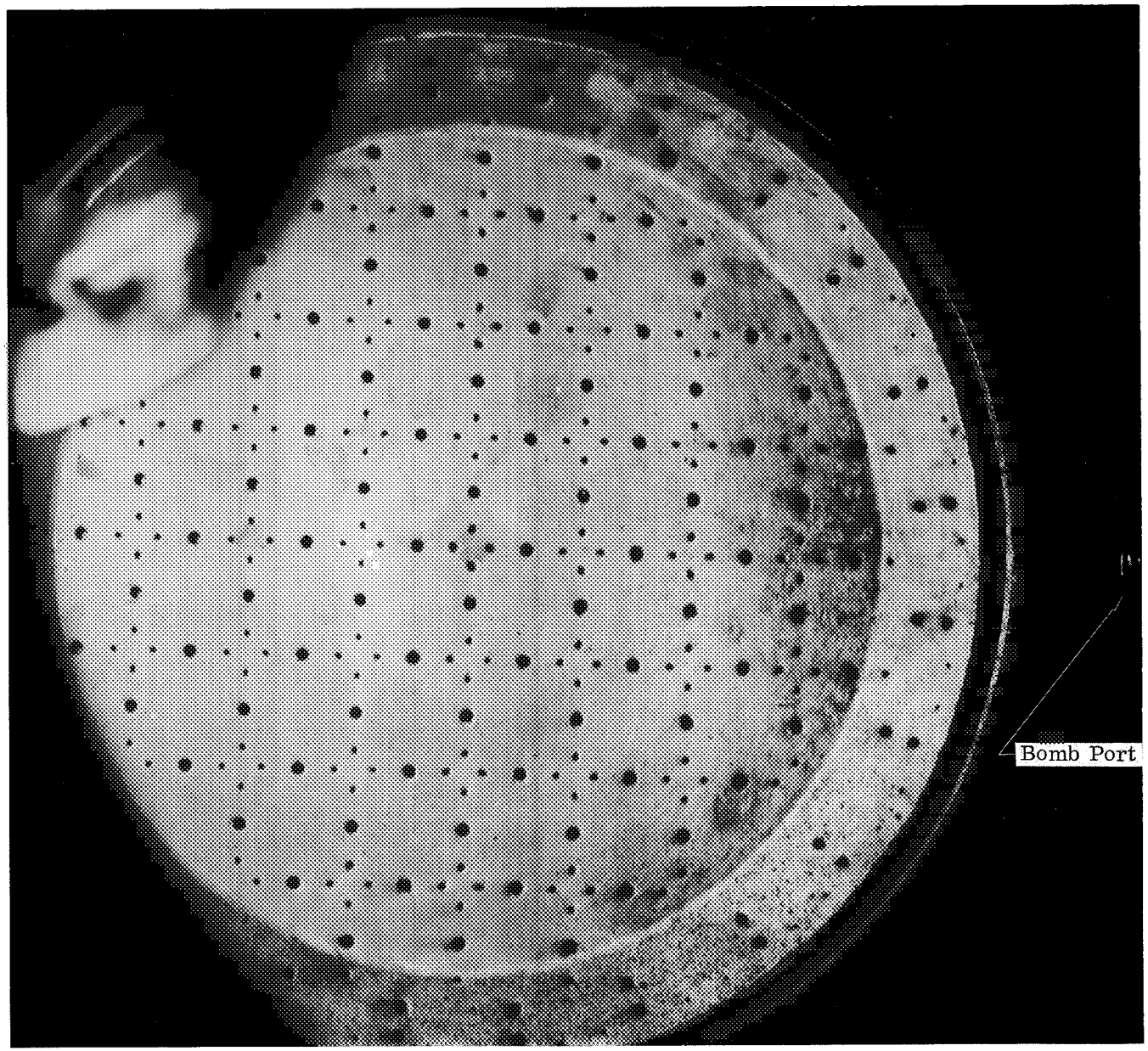


Figure 15. Injector Face Condition Post Test 46 (20 Grain Bomb)

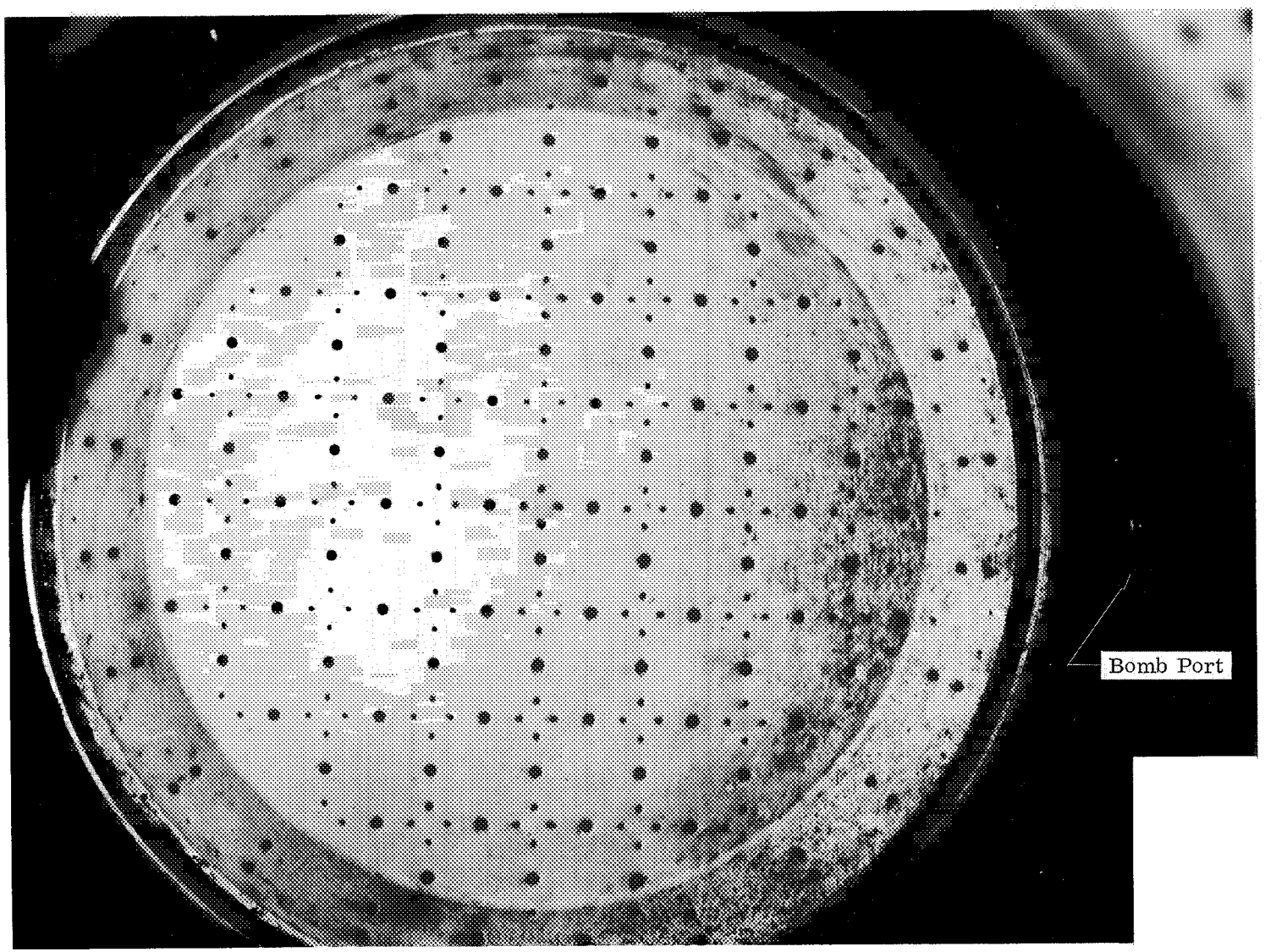


Figure 16. Injector Face Condition Post Test 47 (40 Grain Bomb)

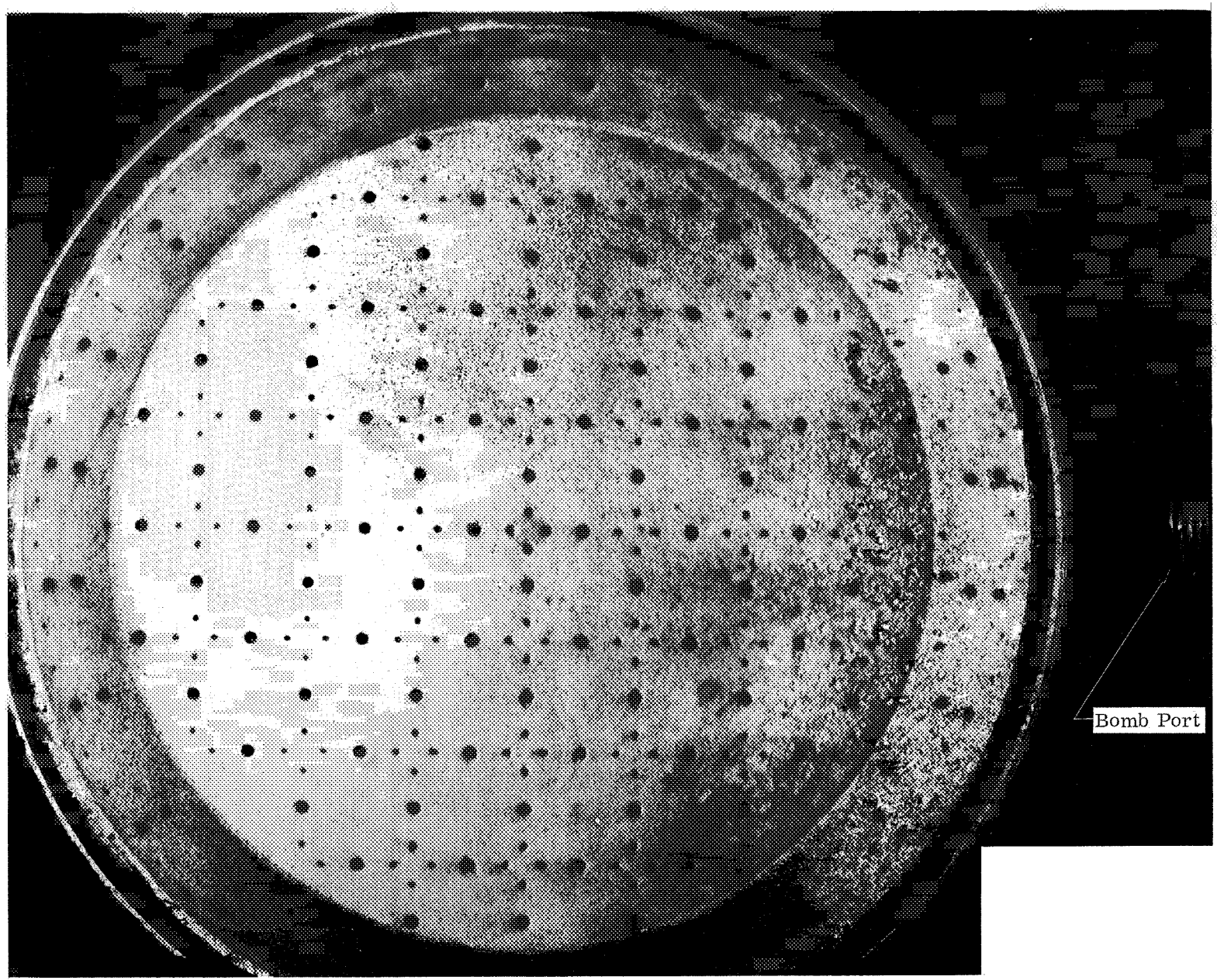


Figure 17. Injector Face Condition Post Test 48 (80 Grain Bomb)

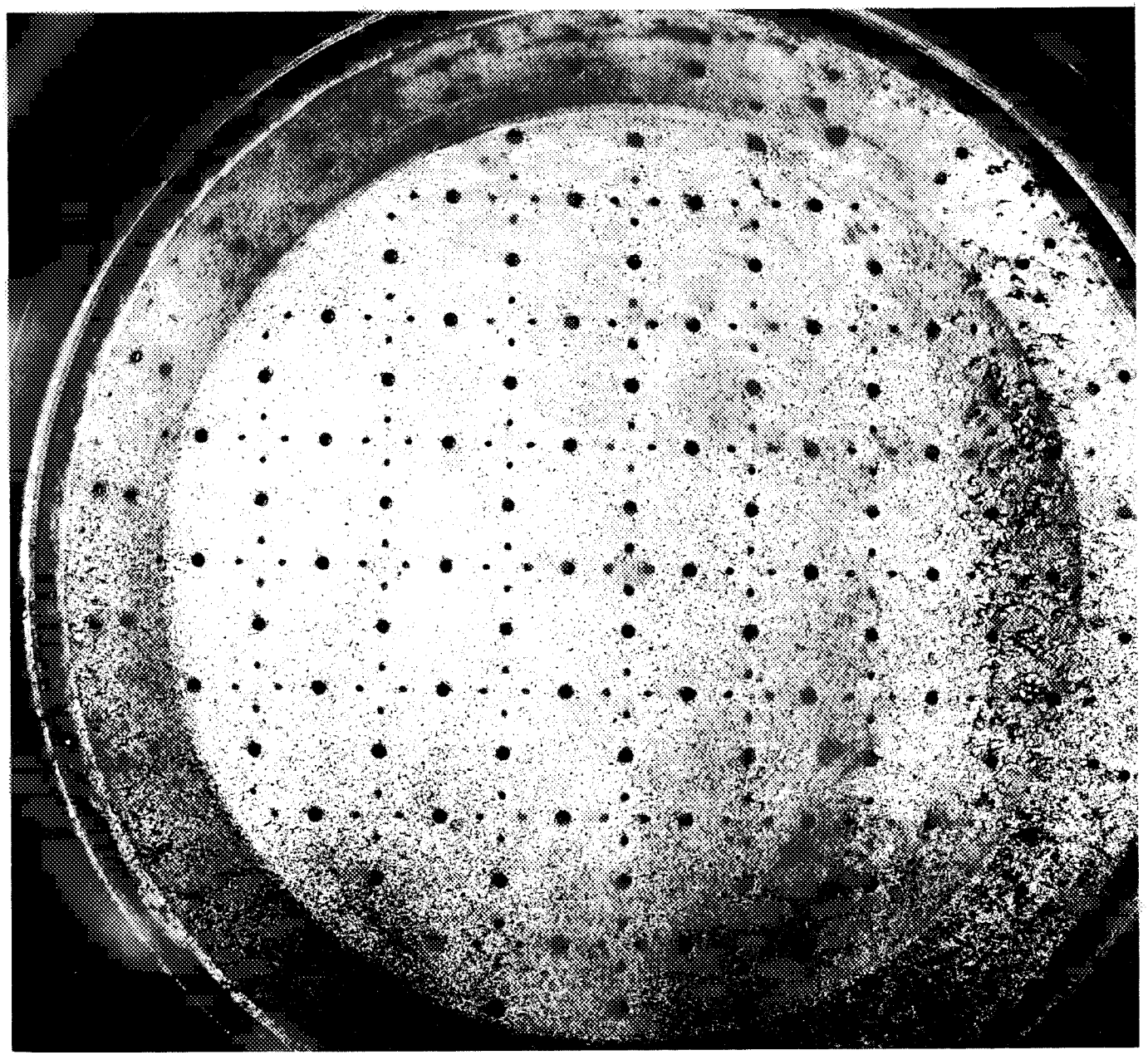


Figure 18. Injector Face Condition Post Test 49 (100 Grain Bomb)

Top

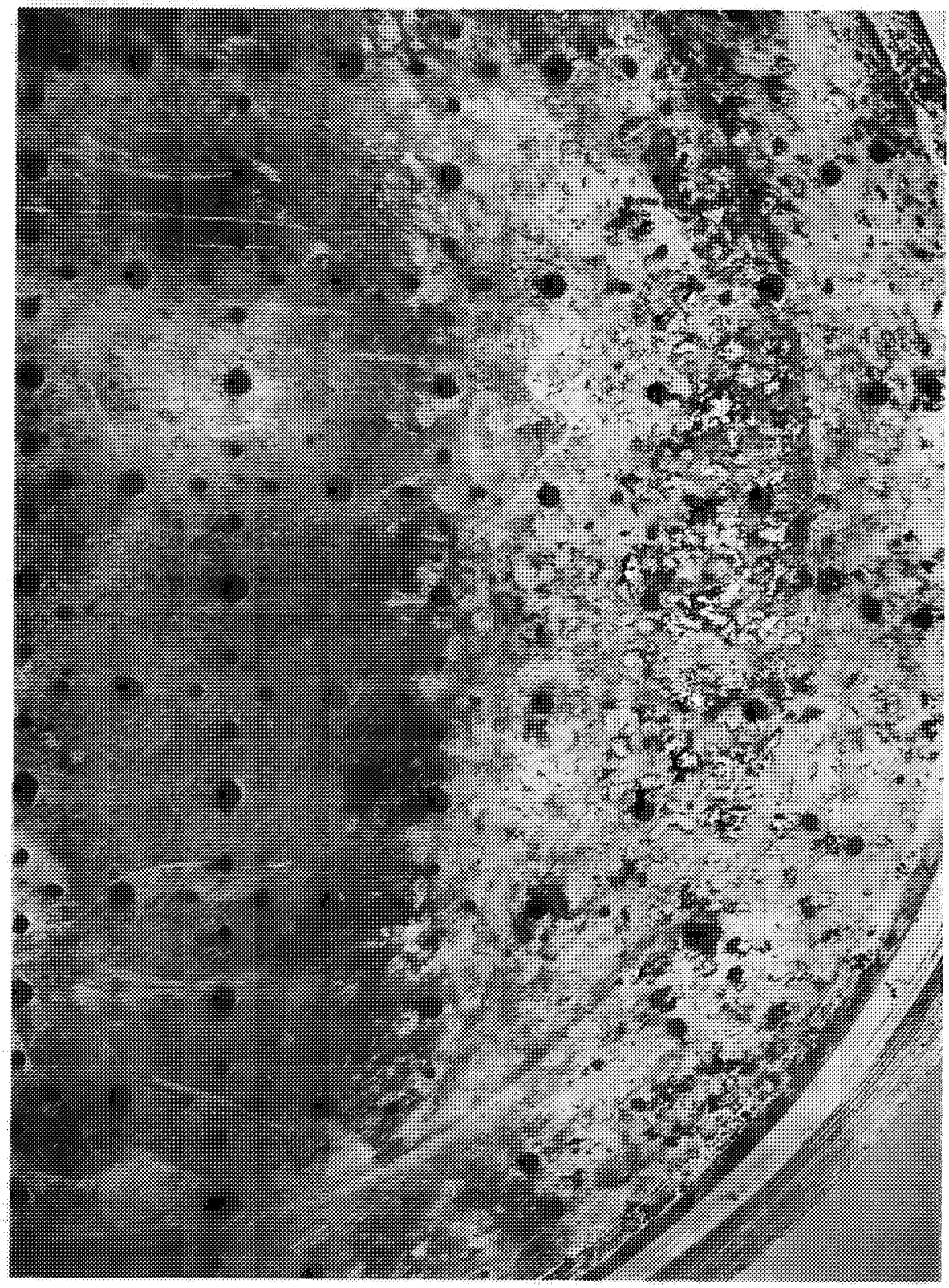


Figure 19. Injector Face Condition Post Test 49 (Close Up View)

3.2 Injector S/N 4B

During the first checkout firing of this unit, prior to stability testing for this program, a failure occurred in which the injector was destroyed. A Failure Analysis Report [1] covers this test. Briefly, the data indicated that the start transient was normal, until 1.791 seconds when combustion instability began (see FM playback run 50 Figure 20) which continued until shutdown at 2.67 seconds. The predominant frequency measured during S/N 4B injector failure was 2600 cps corresponding to the first tangential mode as shown in the pressure amplitude-frequency graph, Figure 21. Also, the higher harmonics of the 2600 cps oscillation are indicated. An automatic shutdown device was incorporated for subsequent tests to monitor combustion oscillations such that shutdown would be effected should instability occur.

3.3 Injector S/N 8

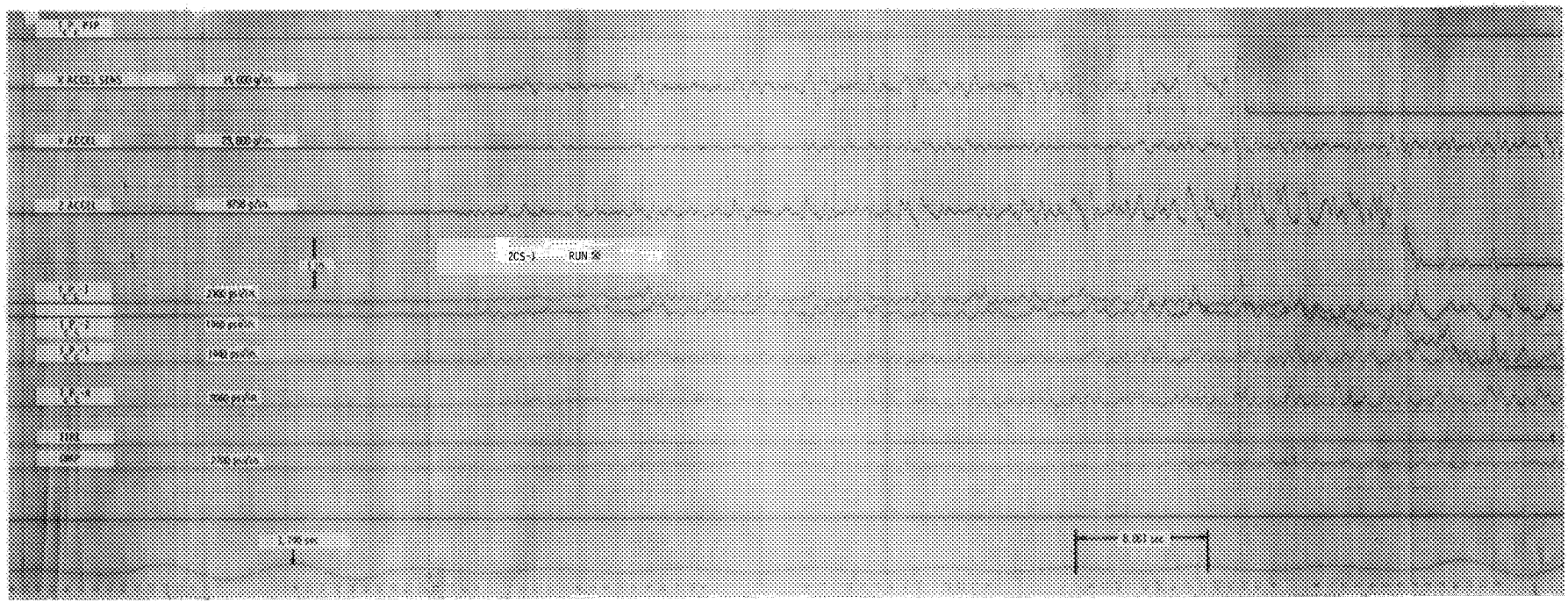
The initial test on this unit resulted in no ignition due to malfunction of the stability monitor automatic shutdown unit (ASD). Test 52 was a successful checkout run. An ASD shutdown occurred on test 53. Referring to the FM playback (Figure 22) it is seen that a damped disturbance occurred at 1.619 seconds, during start, which actuated the ASD resulting in shutdown as indicated by the FFP rise. The disturbance recurred after shutdown. It was postulated that this disturbance was due to the injector nitrogen gas purge introduced into the fuel manifold.

The fuel purge pressure for this test resulted in a manifold static pressure of 7.5 psig. This was adjusted to 3.5 to 4.0 psig for test 54, which reduced the magnitude of the disturbance as can be seen in Figure 23. The purge pressure was reduced again to provide 2.5 to 3.0 psig and the disturbance was eliminated on test 55.

Performance data was obtained with this injector during tests 55, 56 and 58. Performance data in the form of c*, as a function of mixture ratio, O/F, characteristic velocity, is presented in Figure 24.

This injector was then tested for combustion stability without a suppression device during test 59. A 7.9 grain radial bomb was detonated 0.5 seconds of steady-state chamber pressure, and combustion instability was sustained. The FM playback is shown in Figure 25 for the time interval between bomb detonation and shutdown (shutdown

(1) Preliminary Failure Analysis Report, Model 8533 Injector, S/N 4B, Sept. 1967.



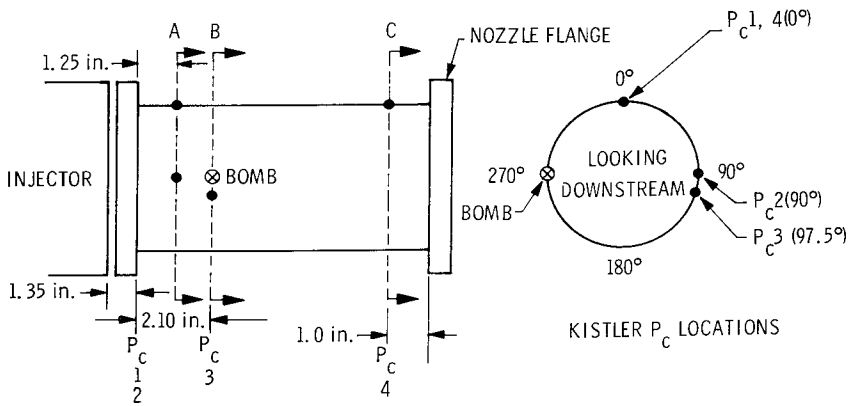
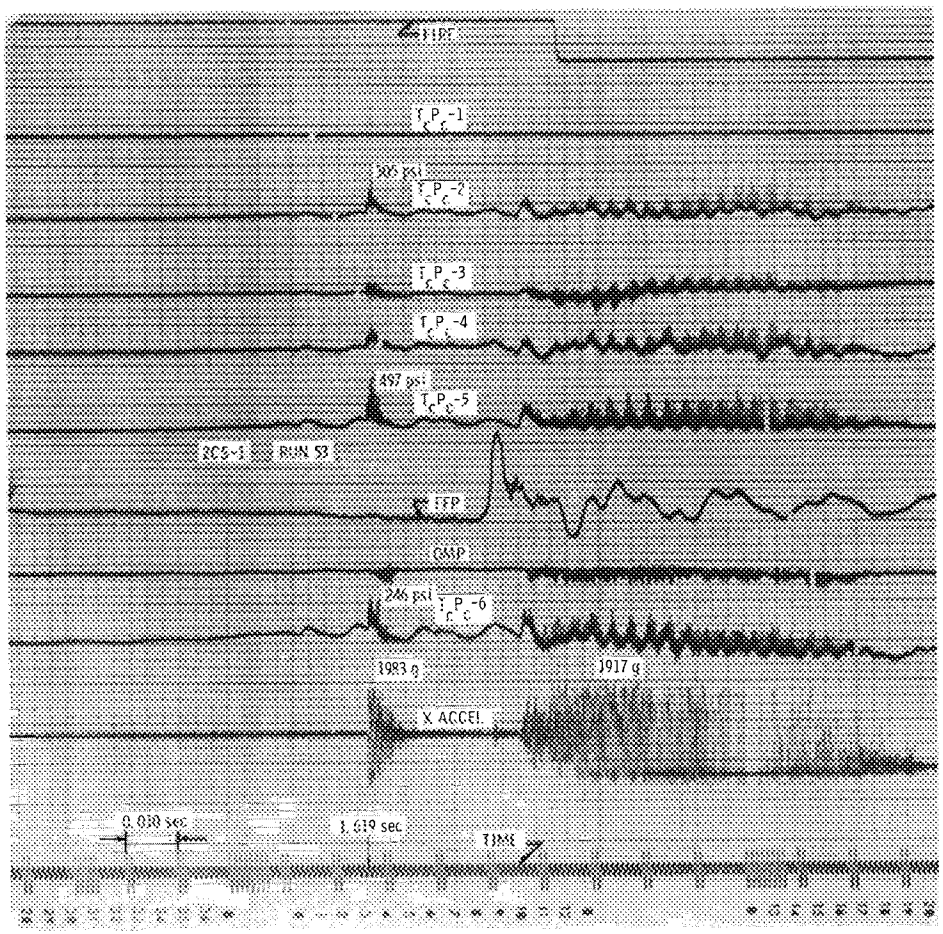


Figure 20. FM Playback (2CS-50)

Figure 21. Pressure versus Frequency (2CS-50) ($T_c P_c$ No. 2)



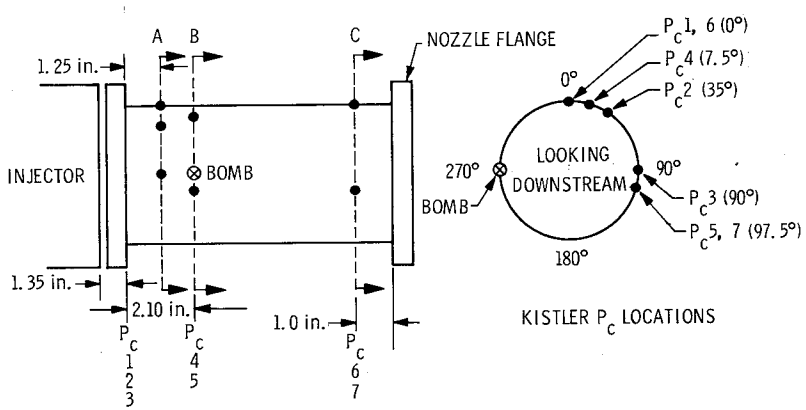
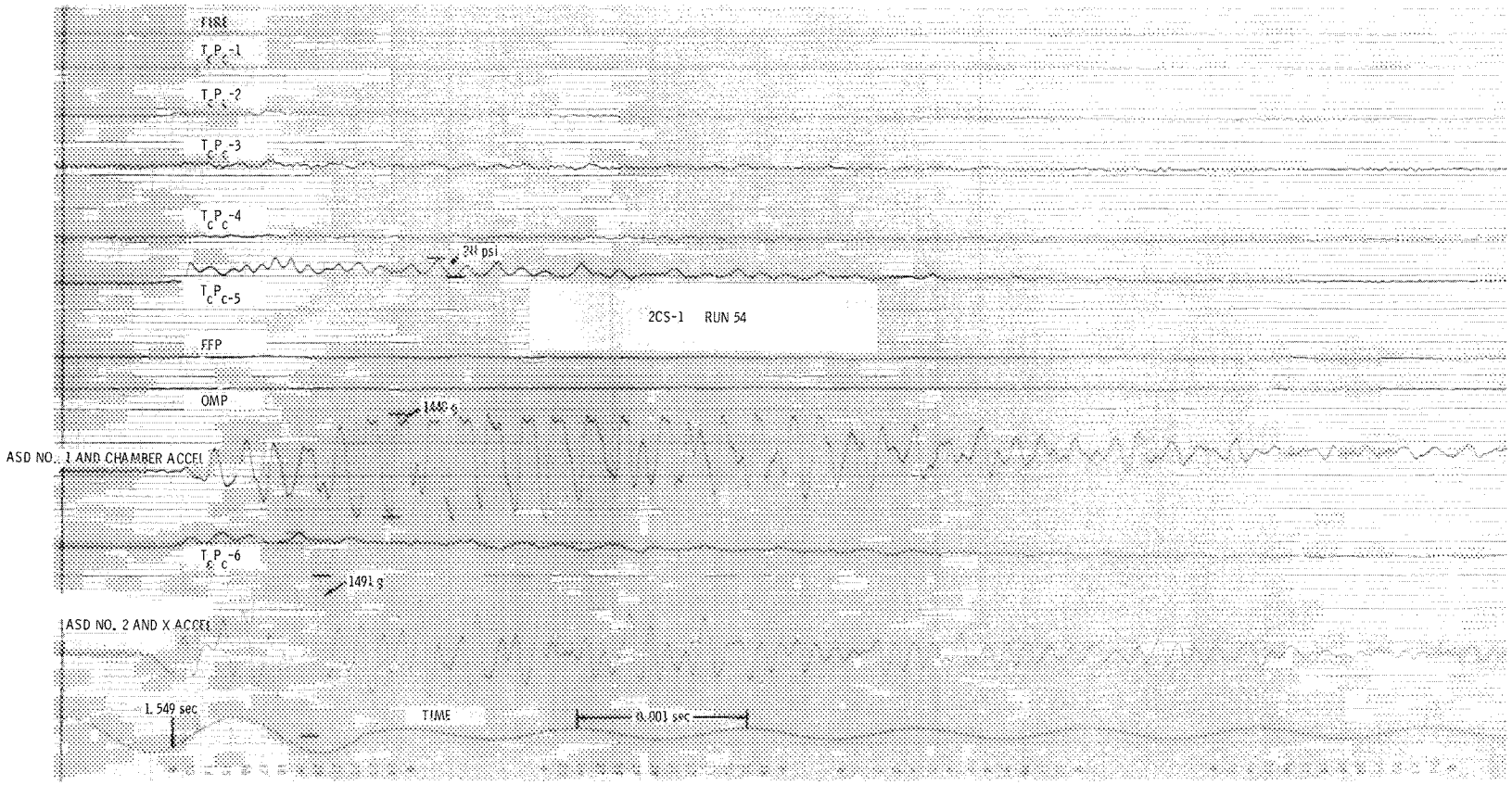


Figure 22. FM Playback (2 CS-53)



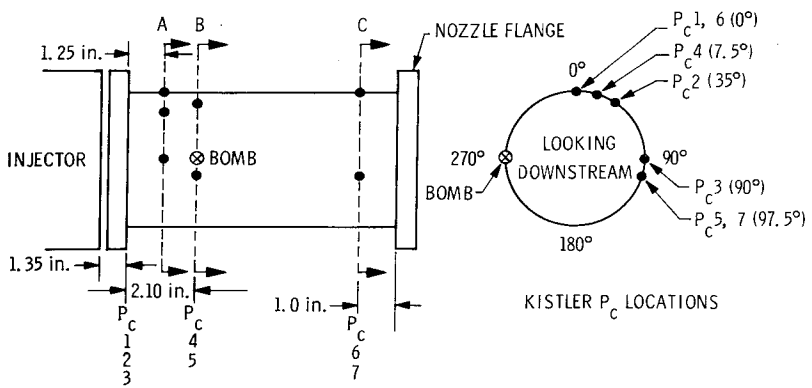


Figure 23. FM Playback (2CS-54)

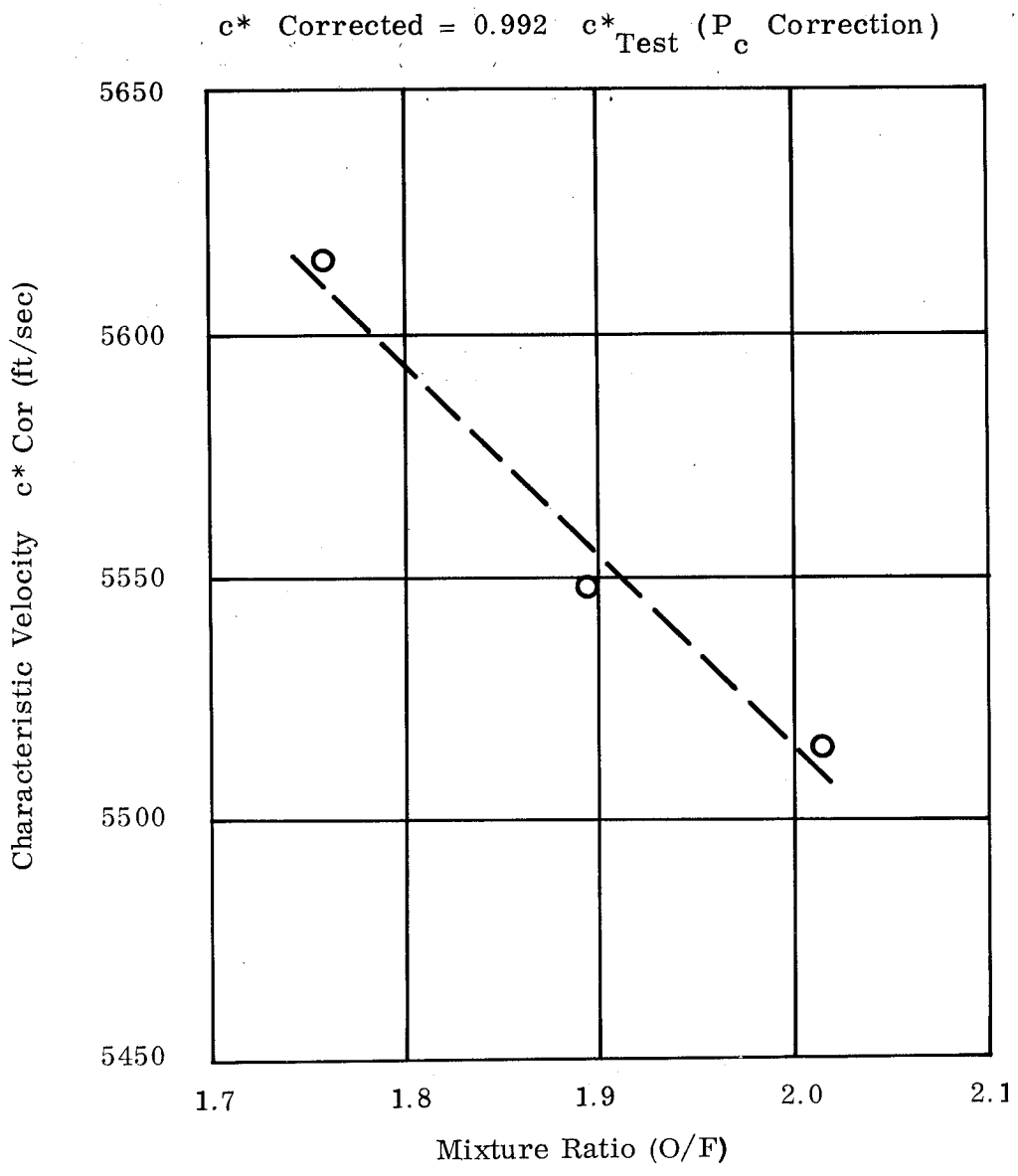
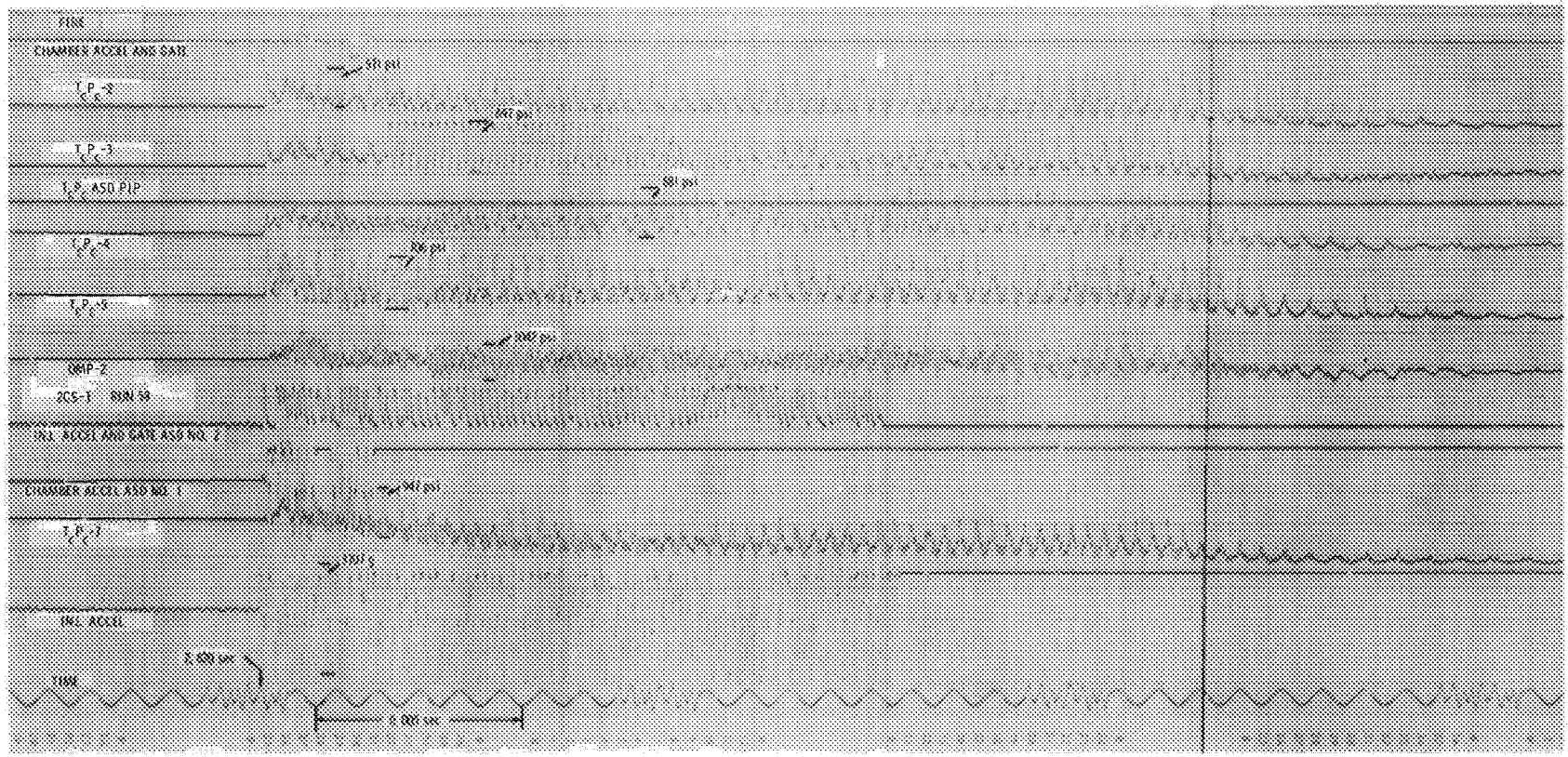


Figure 24. Characteristic Velocity versus Mixture Ratio Injector S/N 8



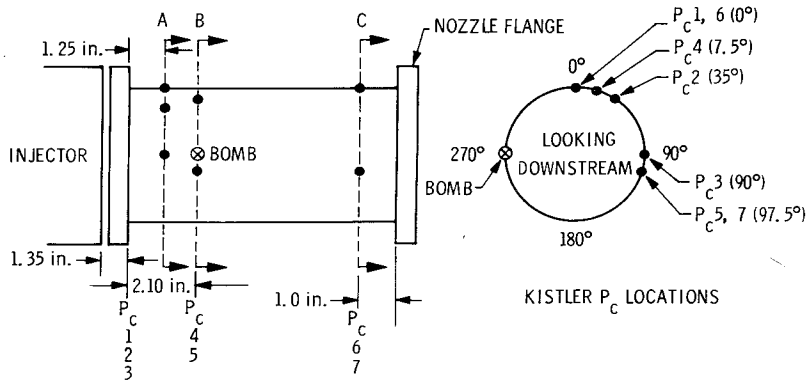


Figure 25. FM Playback (2CS-59) 7.9 Grain Bomb Unsuppressed

Figure 26. Pressure (P_C) versus Frequency (2CS-59) ($T_C P_C$ No. 5)

occurred 22 milliseconds after bomb detonation). Figure 26 shows the pressure amplitude-frequency graph which indicates a fundamental frequency of approximately 2560 cps, corresponding to the first tangential mode.

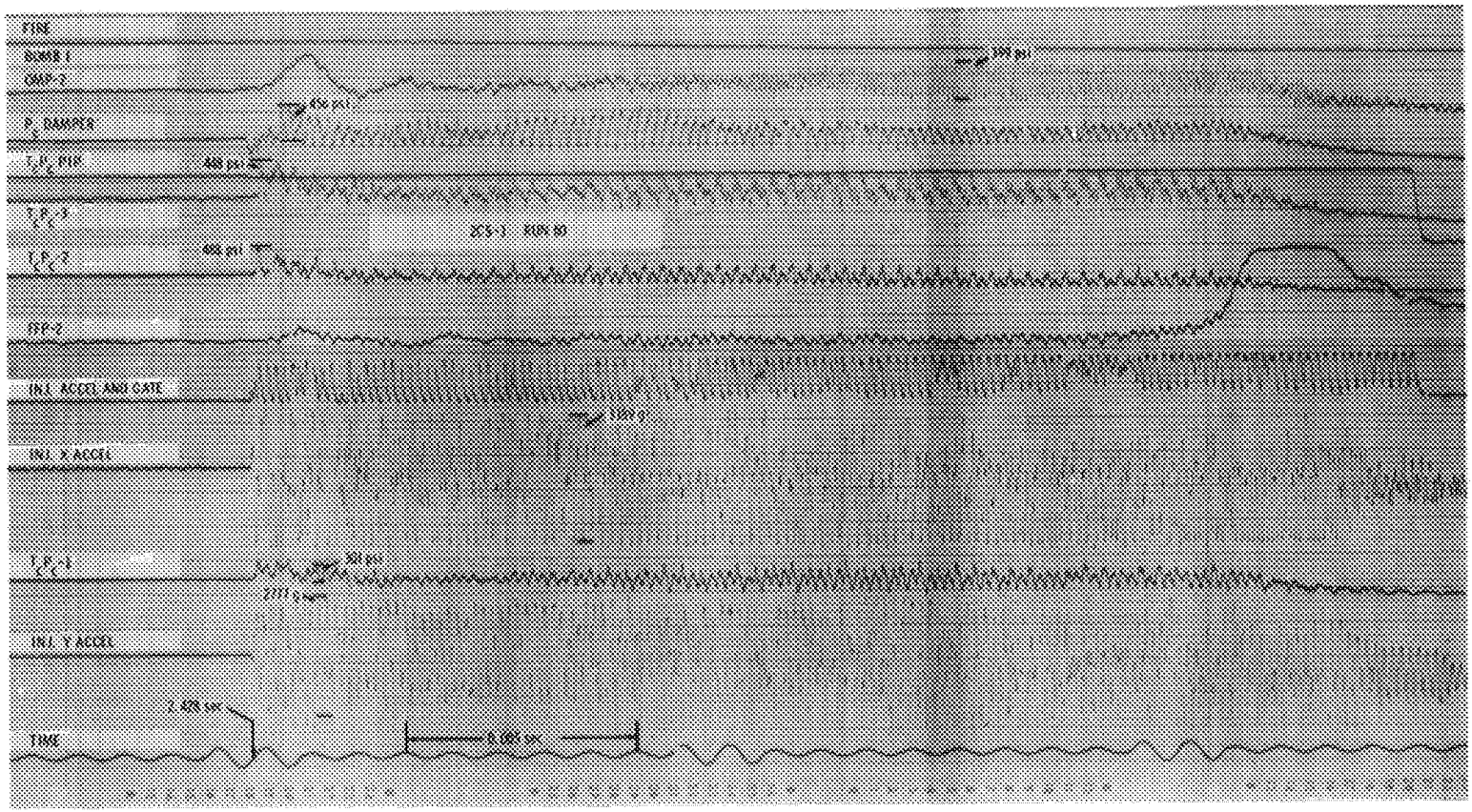
This same injector was then assembled with the start chamber having the acoustic damper incorporated. A 7.9 grain radial bomb was detonated 0.5 seconds after reaching chamber pressure. Combustion instability was sustained as shown in FM playback, Figure 27. (Shutdown occurred 22 milliseconds after bomb detonation as indicated by the FFP pressure rise.) Approximately 60% reduction in chamber pressure peak-to-peak values compared to test 59 (without the acoustic damper) can be observed. The pressure amplitude-frequency analysis graphs for $T_c P_2$ No. 2 which was at the same location as $T_c P_c$ No. 5 for test 59, and the P_c damper located in the acoustic cavity at 7.50 in test 60 are shown in Figure 28 and 29, respectively. The hardware was observed to be undamaged, after this test.

An unshielded thermocouple installed to measure the acoustic manifold gas temperature during test 60 failed. The next test (61) was a longer duration (1.5 second) firing with the same hardware and without bombing. Two shielded thermocouples were installed to obtain acoustic cavity gas temperature. A time history graph of the temperatures together with P_c is shown in Figure 30. The ADT-2 thermocouple was found to be open after the run and therefore is questionable. Based on these data, it was concluded that the acoustic manifold temperature was about 2500°F for test 60 also.

After run No. 61, it was noted that overheating and melt damage was sustained to the acoustic orifices, as shown in Figure 31 and 32. It can be seen in these photographs that the damage was limited to the first two rows of orifices and only at locations that are aligned with barrier doublets.

Although the high gas temperature level measured in the cavity and the orifice damage may be indicative of combustion gas through flow, subsequent disassembly and inspection disclosed no evidence of erosion or overheating within the acoustic cavity.

This device was designed for a gas temperature of 1480°F. A gas temperature of 2500°F, as measured, would result in a tuned frequency of approximately 3660 cps. Therefore, under the resulting test conditions, the acoustic device design was inadequate to damp out the first tangential mode characteristic frequency of 2600 cps.



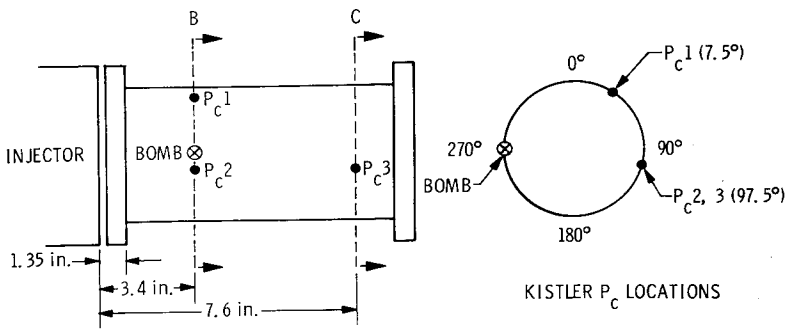


Figure 27. FM Playback (2CS-60) 7.9 Grain Bomb Acoustic

Figure 28. Pressure (P_C) versus Frequency (2CS-60) ($T_C P_C$ No. 2)

Figure 29. Pressure (P_{cav}) versus Frequency Frequency (2CS-60)

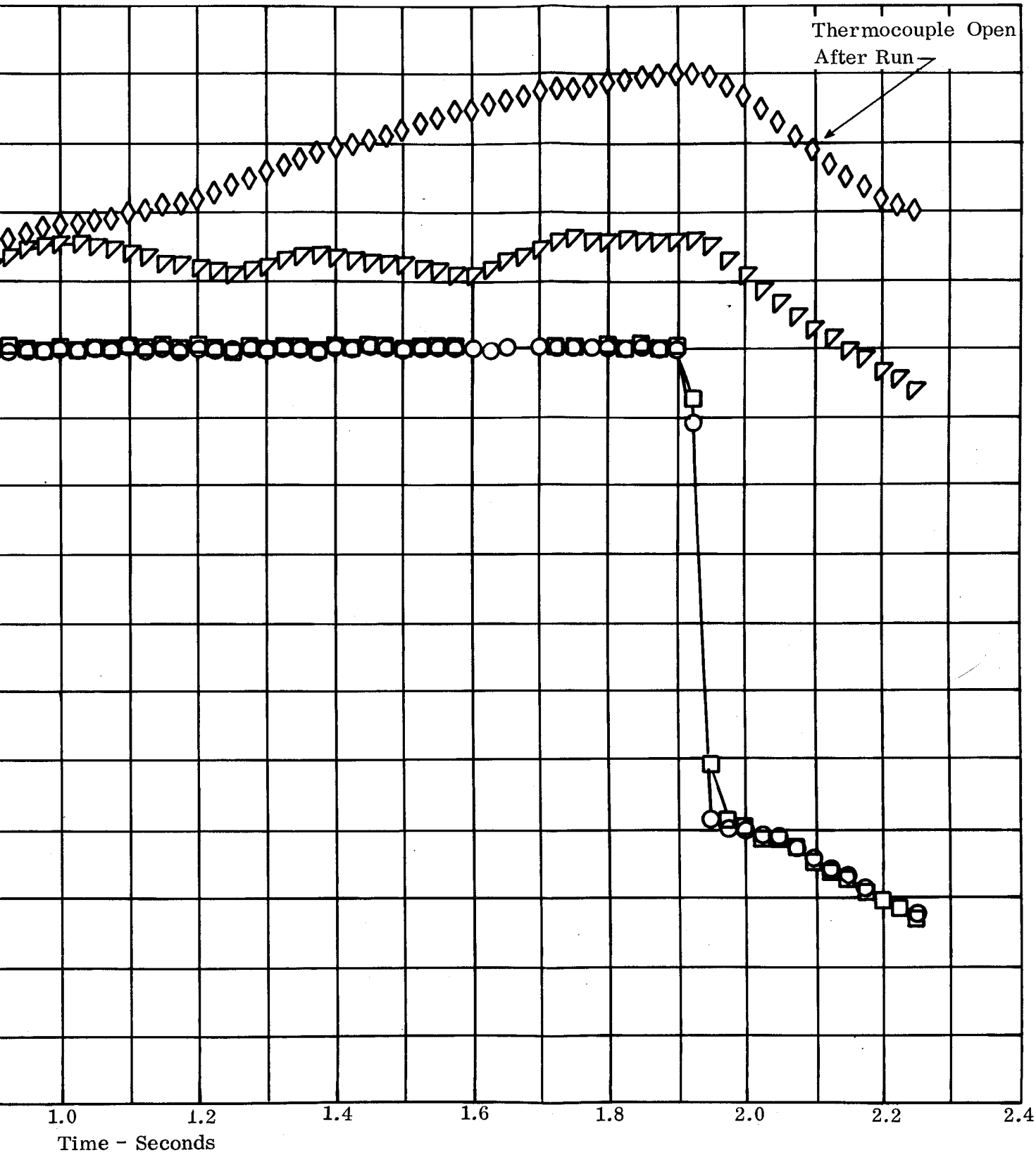
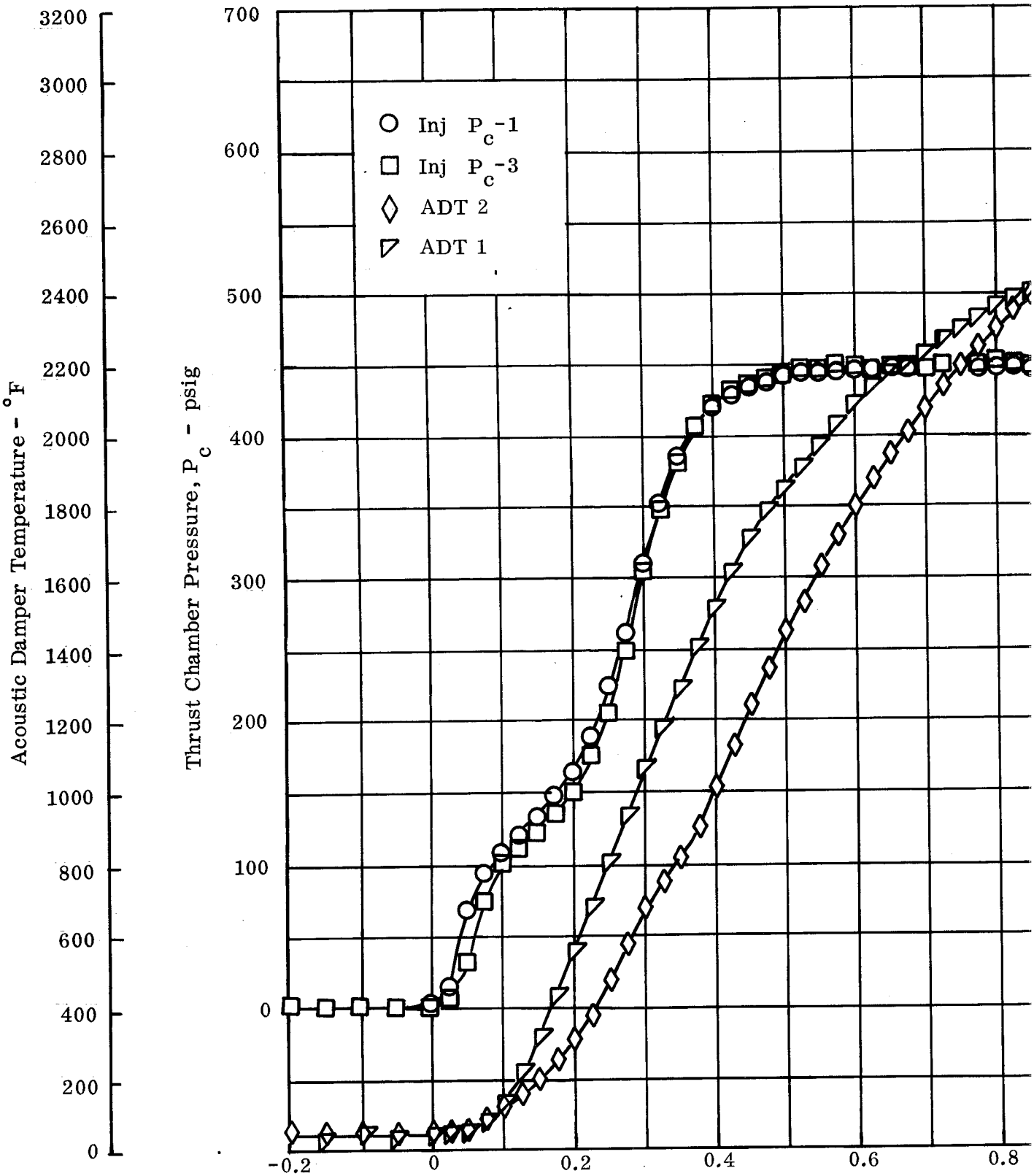


Figure 30. Time History P_c, T_g cav (2CS-61)


Acoustic Damper Temperature - °F
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Thrust Chamber Pressure, P_c - psig
700
600
500
400
300
200
100
0
Inj P_c-1
Inj P_c-3
ADT 2
ADT 1
-0.2
0
0.2
0.4
0.6
0.8

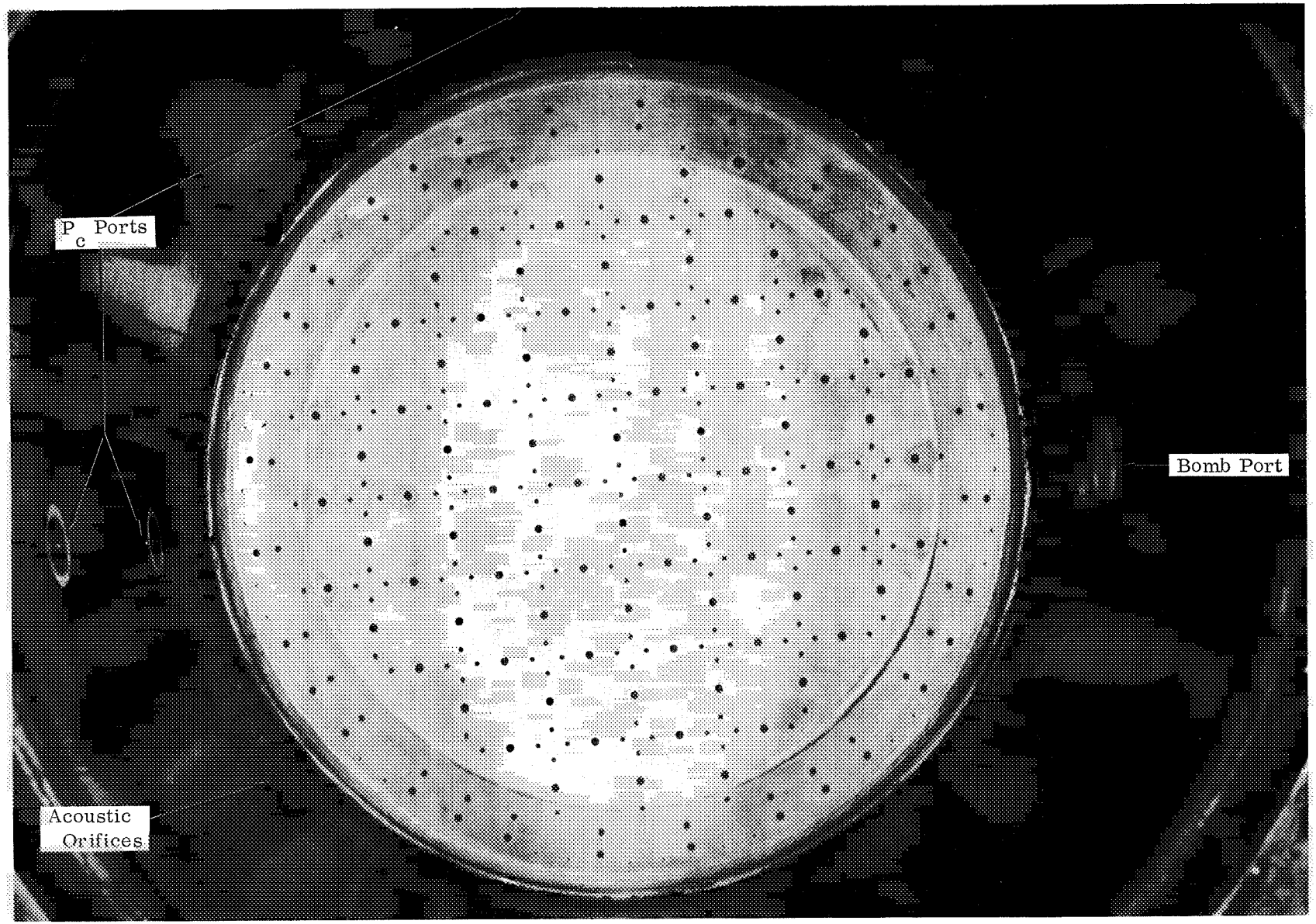


Figure 31. Hardware Condition Post Test (2CS-61) 1.5 Sec Acoustic

Top

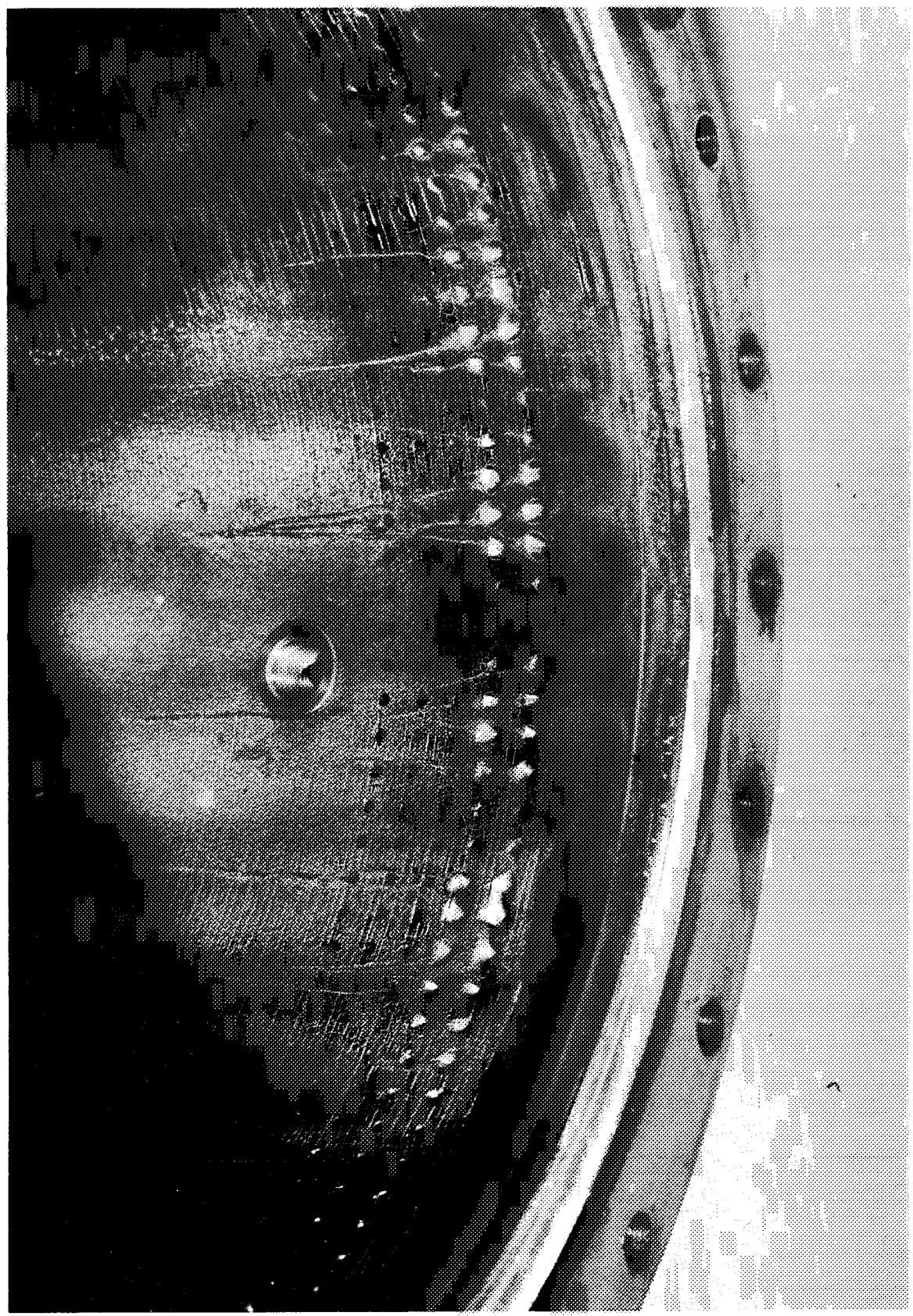
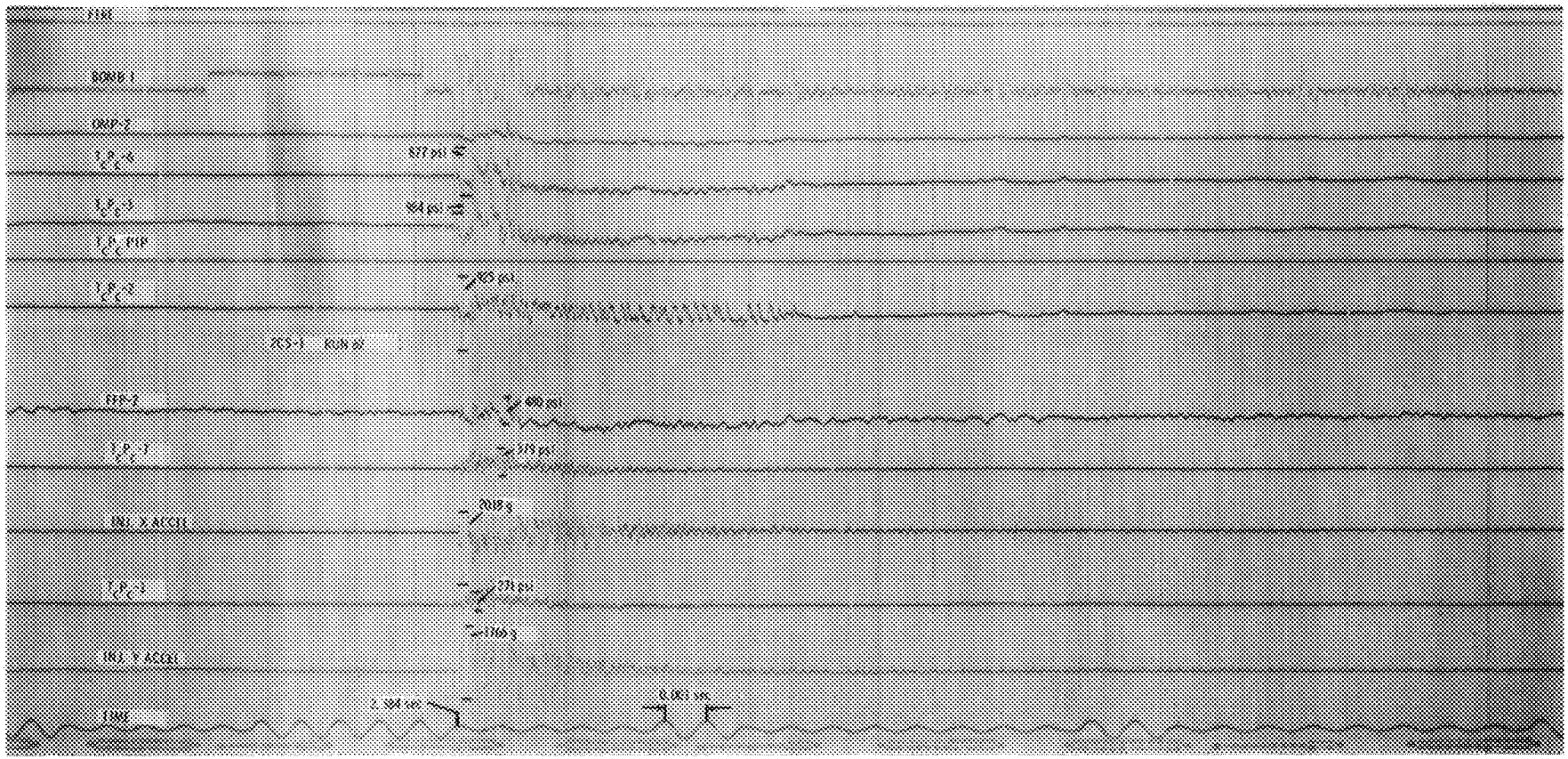


Figure 32. Close Up of Acoustic Orifice Post Test (2CS-61)

S/N 8 injector was then tested with the 3.0 inch length baffle. Figure 8 shows this injector-baffle installation under water flow test. Bomb sizes ranging from 7.9 grains to 100 grains were used in runs 62 to 68 and the baffle damped out the oscillations in all tests. Damped disturbances were observed during the start transients of tests 63, 65 and 66, with the fuel purge manifold pressure maintained at 2.5 to 3.0 psig for all tests. The bomb sizes used were 7.9, 15, 20, 40, 60, 80 and 100 grains. The radial bomb design was used up to and including 20 grains and the axial bomb design was used for the 40 to 100 grain bomb sizes. The FM playbacks for these runs are presented in Figures 33 to 36. It should be noted that there was a large variation between the peak-to-peak chamber pressure oscillations after bomb detonation from transducer to transducer and from bomb size to bomb size. An absolute correlation between combustion overpressure and bomb size was not obtained. Peak-to-peak values did vary from 300 psi to 1200 psi in runs 62 to 68 and the accelerometers ranged from 1760 g's to 4400 g's peak-to-peak.

Figure 37 shows the damp times obtained from the chamber pressure transducers which is defined as the time interval after bomb detonation to attenuate to pre-bomb combustion noise level. Damp times are shown to be increasing with bomb size as expected.

Disassembly and inspection showed the hardware to be unaffected by the bomb test series.



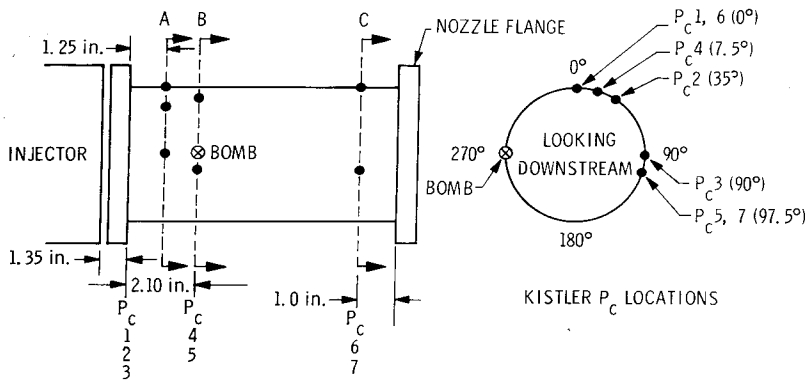
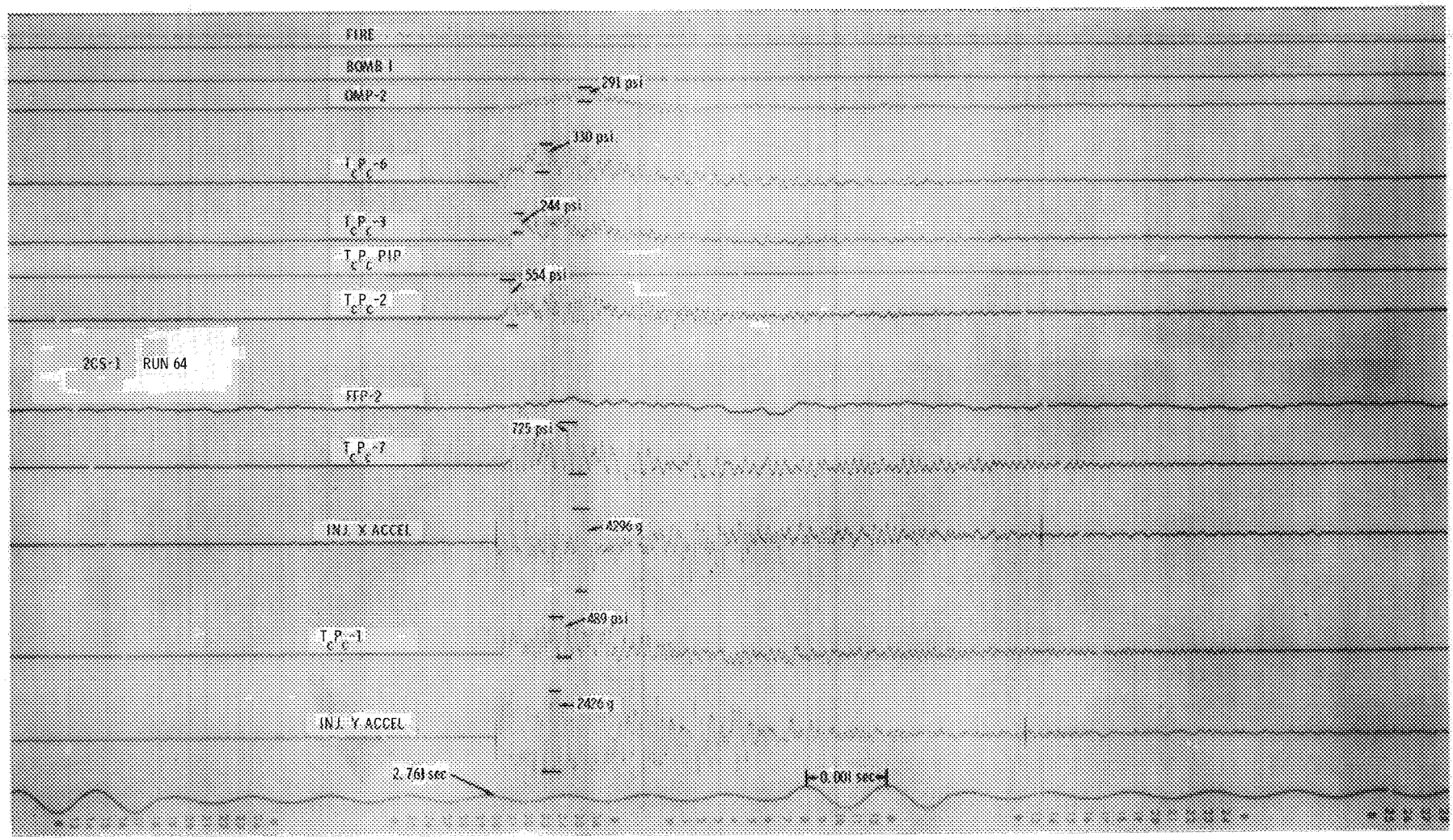


Figure 33. FM Playback (2CS-62) 7.9 Bomb Baffle



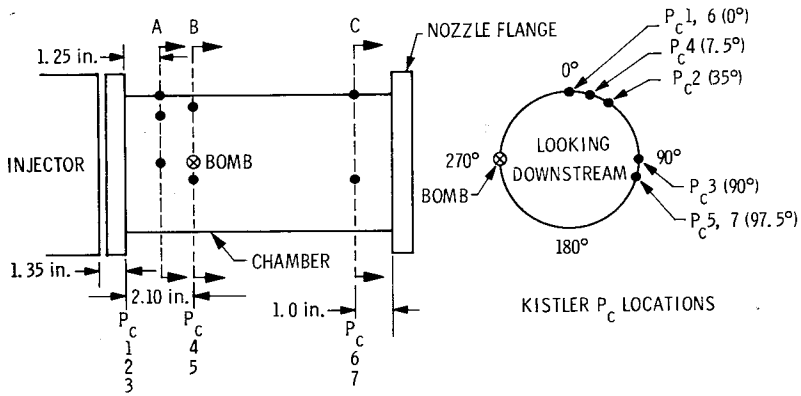
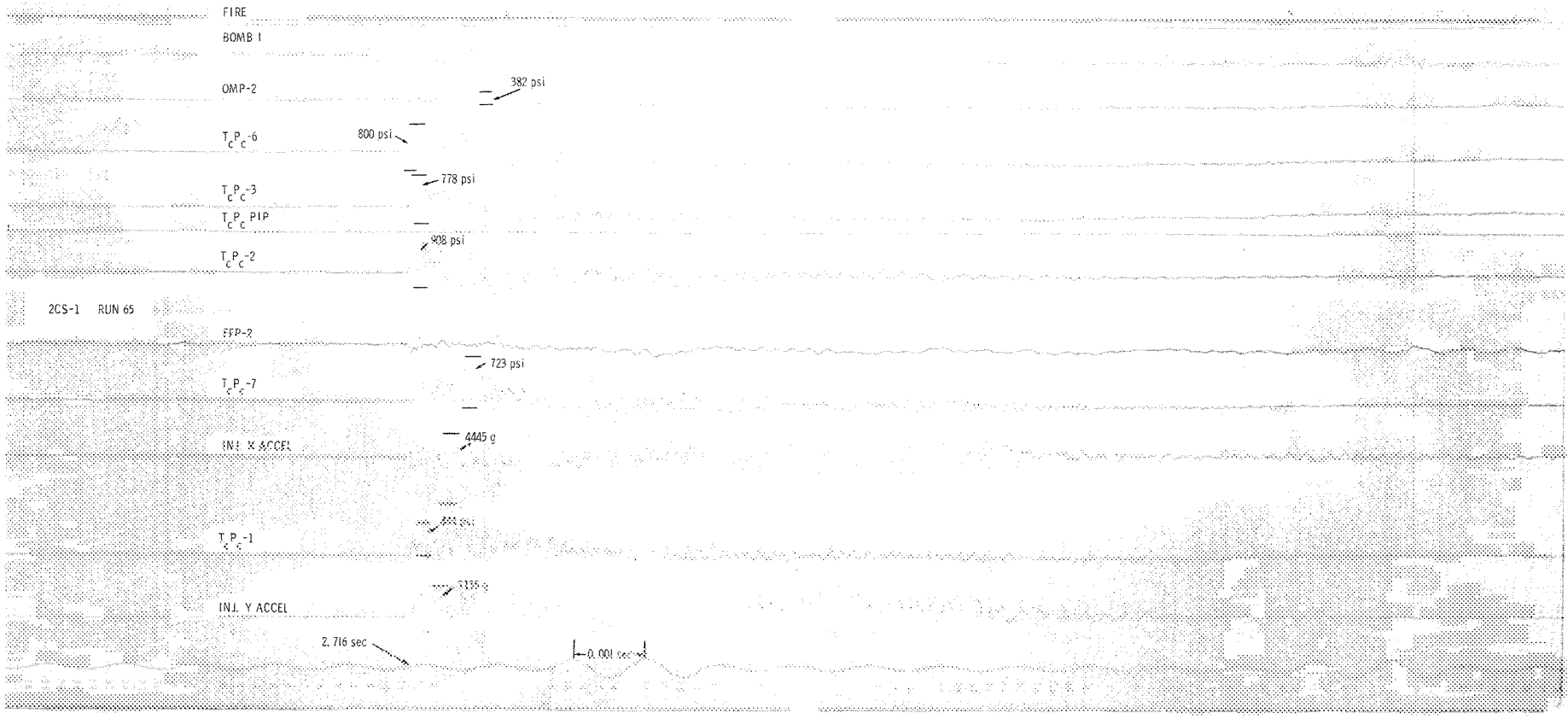


Figure 34. FM Playback (2CS-64) 20 Bomb Baffle



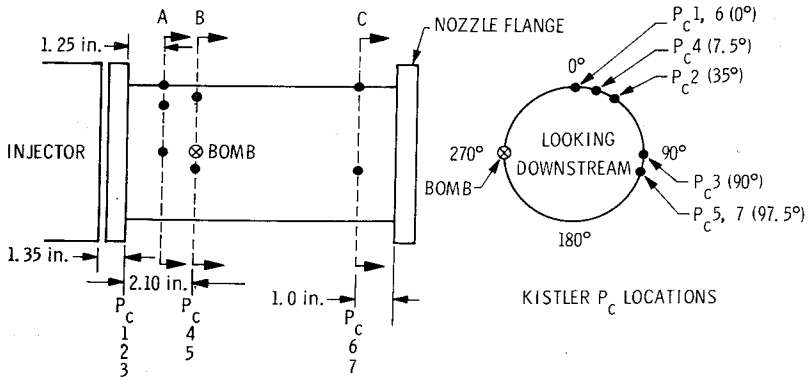
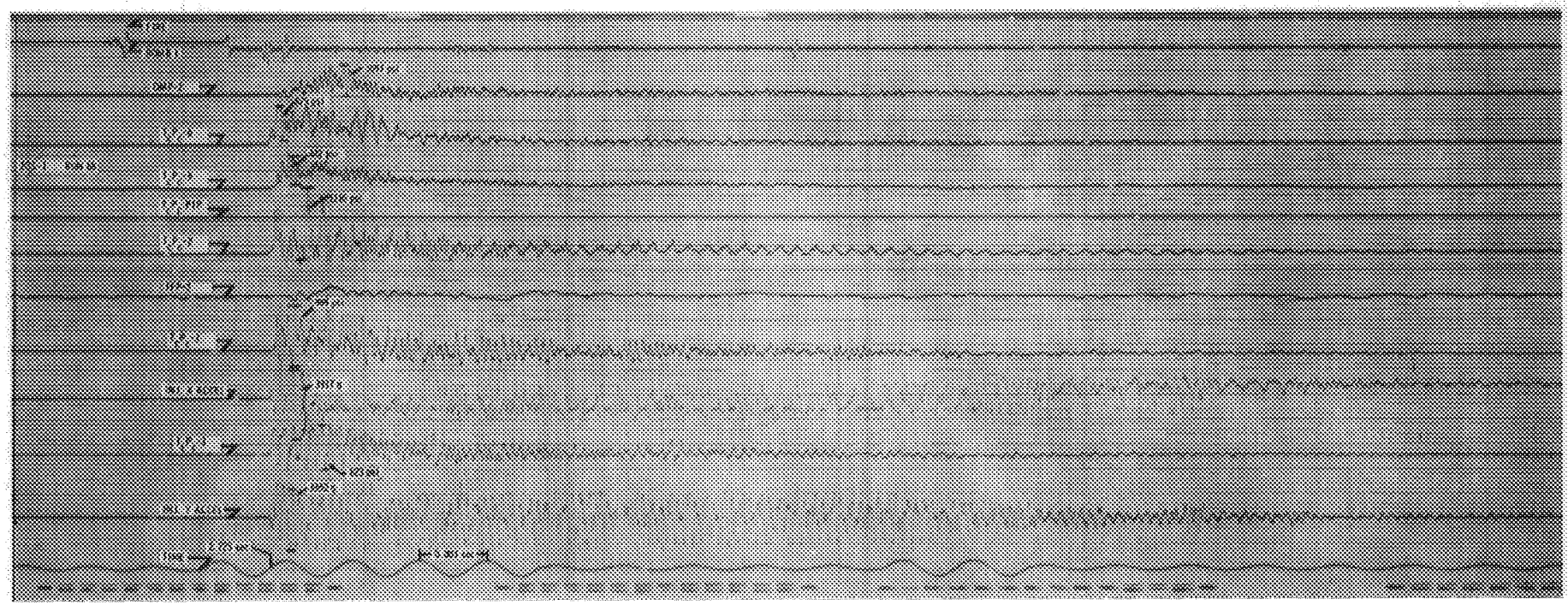


Figure 35. FM Playback (2CS-65) 40 Bomb Baffle



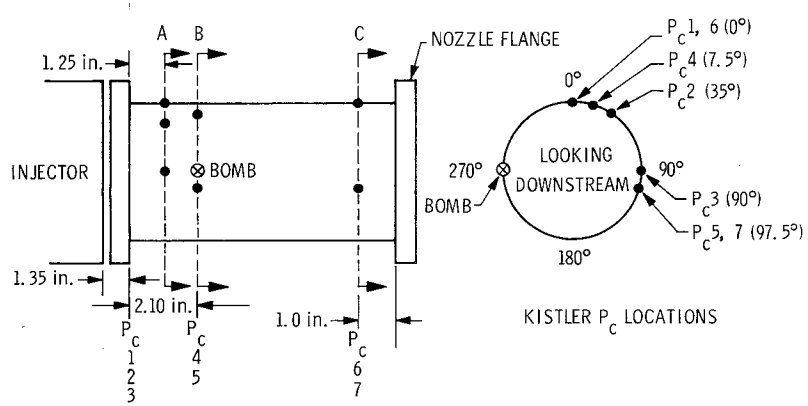


Figure 36. FM Playback (2CS-68) 100 Bomb Baffle

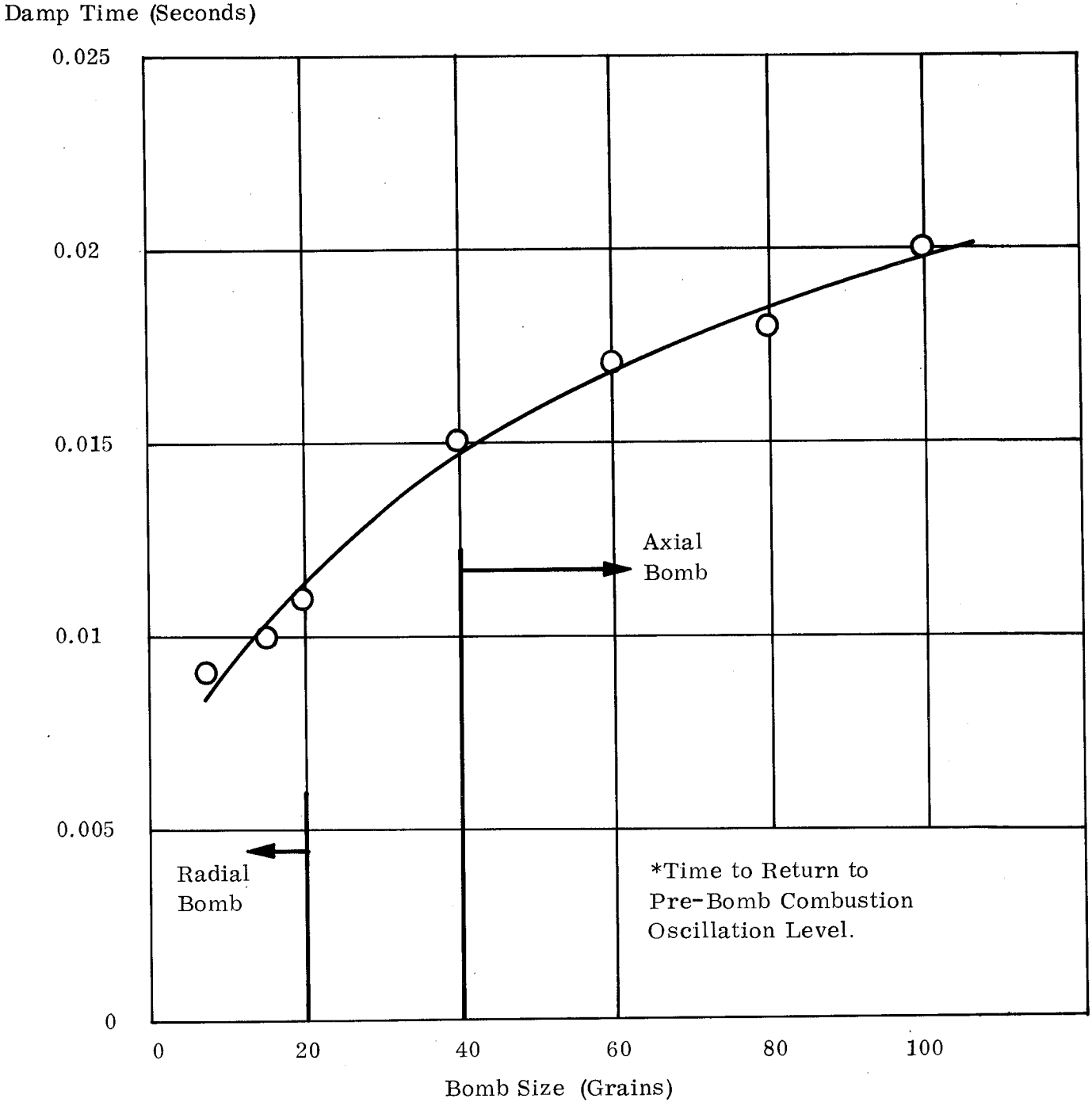


Figure 37. Chamber Pressure Damp Times* versus Bomb Size

4.0 CONCLUSIONS

Grid type injectors, of the S/N 4B and S/N 8 configuration, were dynamically unstable operating with N_2O_4/50-50 Hydrazine Blend. Injector S/N 4B failed due to face burnout which resulted from self-induced combustion instability. Injector S/N 8, unsuppressed and suppressed with an acoustic damper, sustained combustion instability when pulsed with a 7.9 grain charge. Analysis of the combustion oscillations indicated predominant first tangential mode, characteristic frequency. This injector equipped with a four-vaned, three-inch long baffle damped out oscillations resulting from bomb charges ranging from 7.9 to 100 grains. Damp time increased with increasing bomb size. Oscillations were attenuated to the pre-bomb level in 9 and 20 milliseconds for the 7.9 and 100 grain charge sizes; respectively.

Injector S/N 8 c* performance of 5547 ft/sec at 1.9 mixture ratio correlates with the predicted value for this configuration, and meets the Model 8533 performance objective.

It is possible that the high (2500°F) cavity temperature measured during test 61 indicated the temperature of some combustion gas flow through the cavity. Therefore, a significant temperature reduction, approaching the design value of 1480°F in the cavity may be achieved by installing dams to compartment the backing volume, and thus provide static gas conditions.

As a result of the static bomb test series it was concluded that unacceptable shrapnel damage to the injector face was imposed from radially oriented charges of sizes located at Station B equal to or greater than 40 grains. (3.4 inches from the injector.) Therefore, an axially oriented charge holder was designed, and fabricated successfully utilized for the larger bombs.

5.0 RECOMMENDATIONS

It is recommended that further effort be expended during Phase II for both the baffle* and acoustic cavity devices. For the baffle it is proposed to:

(1) Conduct a mixture ratio bomb series with the existing 3 inch vane length unit.

(2) Incrementally reduce the vane length to determine the minimum value which damps out combustion oscillations.

(3) Conduct a bomb test series with various charge locations, and

(4) Measure the baffle surface heating rates to provide design data for the regenerative configuration.

For the acoustic damper it is proposed to compartment the cavity volume to minimize the possibility of combustion gas through flow.

*Subsequent tests under Phase II were conducted: Bomb tests of the 3-inch vane length unit with 100 grain charges at mixture ratios of 1.76 and 2.04 were stable; Bomb tests of a 2-inch vane length baffle at mixture ratios of 1.76, 1.90, and 2.04 were stable.